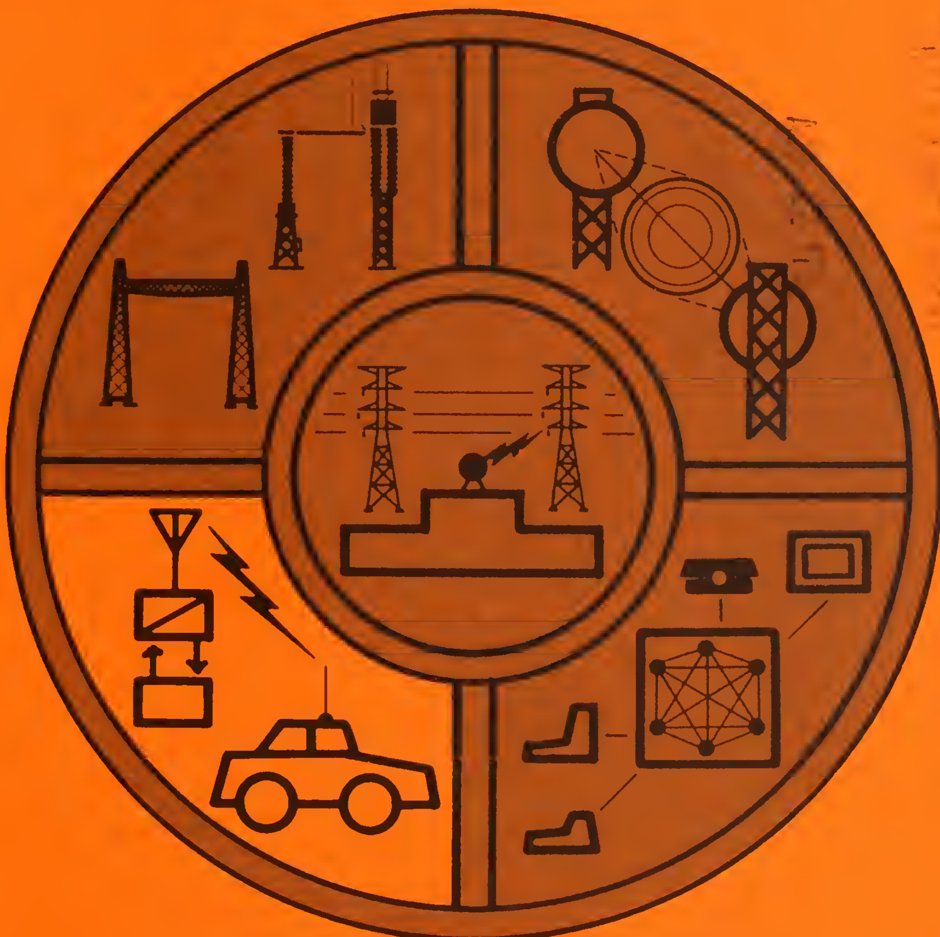
POWER SYSTEM COMMUNICATIONS:

MOBILE RADIO SYSTEMS



REA BULLETIN 66-8

RURAL ELECTRIFICATION ADMINISTRATION • U.S. DEPARTMENT OF AGRICULTURE

JUNE 1978

REA BULLETIN 66-8

POWER SYSTEM COMMUNICATIONS:

MOBILE RADIO SYSTEMS

POWER SUPPLY AND ENGINEERING STANDARDS DIVISION

RURAL ELECTRIFICATION ADMINISTRATION

U.S. DEPARTMENT OF AGRICULTURE

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

TABLE OF CONTENTS

	Page
I GENERAL	1
A. Introduction to Mobile Radio Systems	1
B. Purpose	3
C. Scope	3
D. History of Mobile Radio Systems	3
E. Regulatory Constraints	5
F. Present Systems and Applications	7
G. Trends	9
1. Equipment	9
2. System Design	11
a. Portable Radio Systems	11
b. Antenna Farms	12
c. Data Transmission Equipment and Computers	13
d. Simulcasting	13
e. The 800 MHz Band	14
II SYSTEMS ENGINEERING	17
A. Power Industry Mobile Radio Systems	17
1. Basic Mobile Radio Systems	17
a. Frequency Band	17
b. Types of Radio Channels	21
c. Types of Control Systems	27
d. Typical Basic Mobile Radio System Configuration	28
2. System Examples	35
a. System A	35
b. System B	37
c. System C	37
d. System D	37
B. Systems Considerations	42
1. Current Purpose and Use of Mobile Radio	43
2. Ten and Twenty Year Projected Use of Mobile Radio	44
3. Operation's Routine	45
4. Automation of Operation's Routines	46
5. Policy Impact	47
6. Cost Factors	47
7. Obsolescence	48
8. Alternative Systems	49
9. Summary of Systems Considerations	50

a. Documentation and Analysis of Requirements 50
b. System Concept Options 50
c. Cost Factors 51
d. Grade of Service 51
e. Borrower Resources 52

C. Design Considerations 52

1. System Service Area 53
2. Communications Reliability 53
3. Facility Availability and Acquisition 54
4. Principal Message Format 56
5. System Operational Reliability 58
6. Communications Support Requirements 58
7. Foreign System Interface 59
8. Call Direction 60
9. System Control 61
10. Field Applications 63

D. Design Objectives 64

1. Service Area 65
2. Grade of Service 68
3. Traffic Capacity 72

E. Mobile Radio Equipment 75

1. Introduction 75
2. Land Stations 75

a. Base Station 77
b. Control Stations 77
c. Mobile Relay Stations 80
d. Options and Accessories 80

3. Mobile Stations 83

a. Vehicle-Mounted Stations 83
b. Hand-Carried Stations 86

4. Control Points 88
5. Receiver Selection (Voting) Systems 89
6. Antenna Systems for Land Stations 95

a. Antennas 95
b. Transmission Lines 102
c. RF Signal Processing 104

7. Antenna Systems for Mobile Stations 112

a. Antennas 112
b. Transmission Lines 116
c. RF Signal Processing Equipment 116

8. Power Systems 116

a. Land Station Power Systems 116
b. Vehicular Power Systems 123
c. Portable Power Systems 123

9. Remote Control Systems 124

a. DC Remote Control Systems 124
b. Tone Remote Control Systems 125

10. Tone Signaling Systems 129

a. Continuous Tone Coded Squelch Systems (CTCSS) 129
b. Pulsed Tone Systems 130

11. Data Equipment 132
12. Computer-Aided Dispatch Systems 134
13. Technical Characteristics of Mobile Radio Equipment . 135

a. Transmitters 135
b. Receivers 137

14. Antenna Supporting Structures 142

a. Tall Buildings 142
b. Poles 142
c. Towers 142
d. Broadcast Towers 146

15. Equipment Shelters 147

a. Construction Type and Building Materials 147
b. Interior Dimensions 147
c. Exterior Dimensions 151
d. Equipment Layout 151
e. Interior Facilities and Systems 152
f. Environmental Control Systems 153

F. System Design 157

1. Prediction of Mobile Radio Coverage 157

a. General 157
b. Coverage Calculations 162
c. Detailed Coverage Predictions 163

III OPERATIONS AND MAINTENANCE (O&M) 179

A. Introduction to O&M Philosophy 179

1. Development of the O&M Program 179

a. Traffic Criticality 180
b. System Availability 180
c. Mobile Radio Availability 181

B. O&M Structure and Operation 182
C. Manpower Requirements 183
D. Training 186
E. Support Requirements 187

1. Logistics 187

F. Preventive Maintenance 188
G. Periodic Maintenance 190
H. Test and Evaluation 191

1. Maintenance Echelons 191
2. Levels of Test and Evaluation 192
3. Performance Parameters 195

a. Equipment Operational Parametric Subjects 195
b. Equipment Functional Parametric Subjects 195
c. Equipment Mechanical Parametric Subjects 196
d. Equipment Assemblies Parametric Subjects 197
e. Equipment Specification Parametric Subjects ... 198
f. Equipment Component Parametric Subjects 199
g. System Operational Parametric Subjects 200
h. System Functional Parametric Subjects 201
i. Interface Parametric Subjects 201

4. Performance of Tests 202

IV Bibliography 203

I. GENERAL

During the past 40 years mobile radio has risen from the status of novelty to a serious systems engineering discipline. Modern technological advances in equipment design and performance have greatly increased user acceptance to the point that mobile radio is now considered a natural adjunct to the public telephone network. The complexity of mobile radio technology has likewise increased to achieve ever-improved efficiency, types of applications and cost effectiveness. The explosive growth of mobile radio has fostered the rapid development of standards, engineering practices and regulatory policies and procedures. The mobile radio literature is voluminous and diversified. This Bulletin will provide its users with an overview of the existing information and will present the subject of mobile radio communications from a systems engineering point of view.

A. Introduction To Mobile Radio Systems

Mobile radio systems provide the transmission means for the exchange of information between moving and fixed locations. They connect private or public control centers and telephone networks to radio-equipped vehicles or persons and provide the only communications link for locations removed from ready telephone access. Often the vehicle or man is in motion, causing constantly changing parameters in the radio transmission path, which is a major concern in the design of mobile radio systems. This subject will be discussed in detail later in this Bulletin.

Until the 1960's, the major application of mobile radio was two-way municipal dispatch systems, e.g. police, taxi, fire, ambulance, etc. Two-way dispatch still remains a high priority application, but mobile radio-telephone has achieved wide acceptance as an extension of the public telephone network to the vehicle. Dispatch and mobile radiotelephone are the major applications of concern to the power industry. This Bulletin will concentrate its discussions in these areas. However, the power industry may also have an interest in some of the lesser known applications of mobile radio technology such as personal portable radio, personal paging, data terminals, computer aided dispatch systems, etc. These topics are included, but in lesser depth, making this Bulletin a comprehensive user's design guide.

Typical vehicular mobile radio systems, whether dispatch or radiotelephone oriented, possess many common elements. These are the vehicle-mounted or hand-carried radio and the fixed land or base station radio. The latter generally uses an omnidirectional antenna to obtain uniform radio coverage of an area. Often, the radio and antenna system for the base station are located on top of a high building, broadcast or TV radio tower or a hilltop with a commanding view of the service area of the mobile radio system. The high base station antenna location generally has a reciprocal advantage for

the mobile equipment since it permits optimal "talk-back" range for a given service area. The ideal radio path between a base station and mobile stations is one as free of obstructions as possible. Such a path, when unobstructed, is referred to as being "line-of-sight". High buildings or hills between these stations can cause radio shadows resulting in poor reception.

Common engineering considerations in planning a mobile radio system include:

- The size of the area and the type of terrain over which communications are required

- The selection of an operational frequency or frequencies

- The "control" facilities: number and location of control points; use of special signaling arrangements (i.e. single or two-tone pulse tone equipment; digital dialing equipment, etc.)

- Number of radio equipped vehicles and personal portable radio units

- Potential sources of radio interference

Adequate coverage is the prime requirement of a mobile radio system design. The objective is to identify and eliminate dead spots or noisy reception within the desired radio coverage area. The following factors give some insight into what affects mobile radio coverage:

- Base station antenna height above average ground elevation

- Type of terrain - level, hilly, mountainous, open country or built-up metropolitan areas

- Operating frequency (VHF, UHF or 800 MHz bands)

- Antenna gain (base station and mobile)

- Transmitter power (at base and mobile stations). The limiting factor is generally mobile transmitter talk-back range. Base station transmitters are generally of higher power than mobile transmitters. The systems dispatcher is usually able to reach users in locations where mobile talk-back is difficult. The mobile can move to a more suitable location to talk back when advised of the problem by the dispatcher.

- Ambient electrical noise level at the base or mobile station. Note: Electrical noise is primarily from manmade sources such as power transmission lines, power generators, automobile ignition systems and other radio systems. Such interference must be considered in determining coverage reliability.

- Receiver sensitivity. Mobile and base station receivers are extremely sensitive. The ability to utilize this high sensitivity is often limited by man-made noise levels.

- Transmission line loss between the base station and its antenna

- Heavy foliage which can cause signal attenuation especially in the UHF and 800 MHz bands

B. Purpose

This Bulletin is a design and applications guide for Borrower and consulting engineers with several years of experience. The purpose of the Bulletin is to guide engineers in the application and design of mobile radio communications systems for the power industry.

C. Scope

This Bulletin covers the technical aspects of mobile radio systems from initial consideration of communications needs through design, installation and operation. (Cost analysis is covered in REA Bulletin 66-4.) Bulletin 66-8 presents all the steps required for engineering a mobile radio system. It begins with a general introduction to the subject of mobile radio systems followed by explanations of equipment used, system technical characteristics, system design considerations, analysis and finally operation and maintenance. Elaborate mathematical proofs are eliminated where not necessary to the system design engineer. However, the Bulletin does contain detailed calculation procedures to clearly demonstrate those procedures the design engineer must undertake to effectively engineer a system. To supplement the Bulletin's technical depth, an extensive bibliography is included.

D. History of Mobile Radio Systems

Mobile radio communications has enjoyed a colorful history beginning with the first experiments of the radio pioneers. The startling demonstrations of Hertz in the 1880's inspired the entrepreneur Marconi to seek a market for this marvelous new commodity. Among his early feats was a transmission to a tugboat over an 18-mile path from Needles on the Isle of Wight in 1897. After limited use of radio communications in World War I, the first land mobile radio system was installed by the Detroit Police Department for police car dispatch. The New York City Police Department followed in 1932.

These first systems operated just above the standard radio broadcast band. In fact, they could be freely monitored by the general public simply by tuning to the high end of the dial. As technology and spectrum needs increased during the next decade, the trend was to

use higher frequencies. In 1933 the Federal Communications Commission (FCC) authorized four channels in the 30-40 MHz band on an experimental basis, and ruled for regular service in 1938. World War II imposed a temporary hiatus on installation of commercial systems, but the technological advances made during the war made it possible to exploit even higher frequencies. Experimental work at 150 MHz directed specifically toward mobile radio telephone systems was started in 1945 at Bell Telephone Laboratories. With FCC authorization of a few channels in the 35 and 150 MHz bands, commercial service was initiated in 1946 by the Bell System. A 35 MHz system was installed in Green Bay, Wisconsin, and a 150 MHz system in St. Louis, Missouri. Operation was simplex (push-to-talk) and call placement was handled by a mobile service telephone operator. The mobile customer also had to search manually for an idle channel before placing a call. In 1956, the same type of service was introduced on the newly authorized channels of the 450 MHz band. Work continued at Bell Laboratories and other places with the twofold objective of improving existing service and development of the higher radio frequency bands.

In 1964, a new 150 MHz radio telephone system was made available which provided full duplex service, automatic channel search, and dialing to and from the mobile station. This was termed IMTS by Bell for "Improved Mobile Telephone System". In 1969, the same kind of improved operation was introduced in the 450 MHz band.

After World War II other kinds of mobile radio service came into being. These generally operated at frequencies below 460 MHz and provided service to specialized groups falling into three main classes:

- The Public Safety category (police, ambulance, civil defense, fire, rescue and other units associated with local government activities)
- The Industrial and Land Transportation category (taxicabs, truckers and haulers, oil distributors, forest products, manufacturers, railroads, general businesses, newspapers, and power utilities)
- Private individuals (who were given the opportunity to use mobile radio for personal purposes with the establishment of Citizens Bands at 450 MHz and below)

In the decade of the 1970's the FCC opened two new frequency bands for mobile radio systems: the 470 to 512 MHz and 806 to 866 MHz bands. The 806 to 866 MHz band provides two 15 MHz blocks of spectrum 30 MHz apart.

Thus, since the beginning days of mobile radio-telephone in the early 1920's, the picture has been one of steady growth and advancing technology characterized by a demand for service that has exceeded available system capabilities and frequency spectrum.

E. Regulatory Constraints

The brief history of mobile radio summarized above can only be regarded as a prelude. The ultimate objective of mobile communications is to enable anyone on the move to communicate instantly, easily, and effectively with anyone else. The fundamental problem is lack of radio frequency spectrum to handle the demand for service within the state of the art of economical hardware and systems.

The FCC acts as custodian of a limited natural resource - the frequency spectrum - and must balance the sometimes conflicting needs of the different services required by the public. It is the regulatory body to which the mobile radio system engineer must justify the system need and other technical matters. A major system requirement which must be resolved with the FCC is that of frequency assignments. Frequencies available to all classes of users other than Federal Government agencies, and other pertinent details, are listed in the FCC Rules and Regulations. Those of particular interest to the Borrower are:

- Volume I, Parts 1 and 17
- Volume II, Part 2
- Volume V, Parts 89, 91 and 93 (The FCC will simplify and consolidate these three parts into a single part, Part 90.)

Federal Government agency and department users receive their radio frequency allocations from the Inter-Departmental Radio Advisory Committee (IRAC).

With some exceptions, most classes of users are allocated blocks of frequencies in each of the mobile bands. With the advent of the FCC Chicago Frequency Management Center, the block system is being supplanted to some degree by the pooled concept whereby frequencies are shared by many classes of users. An important part of mobile radio application engineering is the correct choice of a frequency band, and the particular frequency (or frequencies) which will be best suited for a given system.

Part 91 of the FCC Rules contains complete information regarding assignment of frequencies, procedures for obtaining radio station authorization, technical standards for equipment, and station operating requirements. Part 91, Subpart F, defines the specific rules for the Power Radio Service, the radio frequencies available for this service and the limitations imposed on the use of specific frequencies.

In general, when a user is ready to request a mobile radio station authorization from the FCC he must submit FCC Form 400 (except for applicants in the Chicago area who submit Form 425) together with all necessary supplemental information.

An important item of supplementary information is the evidence of frequency coordination. The applicant may perform the frequency selection and coordination himself or he may request a frequency advisory committee to perform this service. The latter method is preferred. The utility industry has established the Utilities Telecommunications Council (UTC) to represent its telecommunications interests before the FCC, other Federal and State agencies and common carriers. UTC, through its Frequency Coordination Section which includes regional "Frequency Coordinators", and a national, computerized radio frequency data base, provides frequency selection and coordination services for power industry mobile radio users.

Use of specific frequencies in the spectrum allocated to the Power Radio Service is subject to many limitations. The limitations listed below are general and subject to exceptions:

- Frequencies assigned as "mobile only" cannot be used by fixed or base stations.

- Mobile relay (repeater) operation is only permitted on frequencies above 450 MHz.

- The 470-512 MHz band (which occupies the spectrum originally assigned exclusively for TV Channels 14-20) is authorized only in the following urbanized areas: Boston, Chicago, Cleveland, Dallas, Detroit, Houston, Los Angeles, Miami, New York, Philadelphia, San Francisco and Washington, D.C. Use of this band is subject to many restrictions on transmitter power output and antenna height due to possible TV interference.

- In the 806-866 MHz band there are a variety of restrictions, principally on transmitter power output and antenna height, depending on the type of system proposed (i.e. trunked or conventional), location with respect to a geographic center of an urbanized area, and radius of service area.

Other important items of supplementary information which must be submitted to the FCC together with the request for radio station authorization include:

- Statements justifying the need for more than one frequency

- Functional system diagram and detailed description of the operation of the proposed system

- For frequencies in the 470-512 MHz band: average terrain elevation data, effective radiated power computation and distance to protected television station

- Environmental impact statement (required generally for "major" new systems)

- FCC Form 400-S (for 806-866 MHz band requests)

Applicants should review the applicable FCC Rules carefully prior to submission of requests for radio station authorization to avoid rejection of application and time delays. Due to the complexity of the rules, it is recommended that new system applicants solicit professional assistance from consultants or the UTC.

A second Governmental agency exercising regulatory power over radio installations is the Federal Aviation Administration (FAA). The basic concern of this agency relative to mobile radio systems is hazards to air navigation caused by antenna towers. From the practical side, as this affects the radio system designer, the FCC Rules and Regulations include the FAA requirements, but do not supplant the application to the FAA for approval of antenna structures under defined conditions.

F. Present Systems and Applications

The Power Radio Service includes, "persons (as) eligible to hold authorizations to operate radio stations", from the following partial list of primary endeavors:

- The generation of electrical energy

- The transmission of electrical energy

- The distribution of electrical energy

- The distribution of manufactured or natural gas by pipeline

- The distribution of water or steam by pipeline

- The distribution of water by canal or open ditch

- The collection, storage, purification or transmission of water preparatory to distribution

- The generation of steam preparatory to distribution

Consideration of the above indicates that a generalization is in order to include any "person" or "persons" engaged in the field of energy or utility supply to the general public as being eligible for radio authorization. This point is made in order to illuminate

the impact of such diversified endeavors upon present mobile radio systems. It is necessary for the Borrower to keep in mind the particular application of his mobile radio system, and not copy one that has proved satisfactory in another segment of the power industry.

Power industry use of mobile radio today can be roughly divided into two major business charters:

- Generation and long distance transmission
- Local area distribution to consumer

Both are self-contained spheres of influence with operations and performance requirements that do not necessarily exist in parallel within a given segment of the power industry. To illustrate: long-distance transmission systems are conceived with the intent to provide an uninterrupted supply of energy; local area distribution systems are conceived with the intent to accommodate random interruptions in the supply of energy to its consumers. The application of mobile radio communications therefore would appear as being different, and the radio system configurations should be assumed responsive to the individual needs of the two examples. Analysis of present mobile radio systems does not bear this out. The needs of the individual segments of the power industry have been forced into a common radio communications concept based upon traditional dispatch systems.

Present power industry mobile radio systems are generally manually operated and dispatcher oriented. In most systems, if the man in the field does not initiate a call to his base, the dispatcher has no positive means to contact him or leave a message except by voice call. Information and data transactions between field and base are often logged by hand, and manually controlled. Priority and emergency communication calls require human recognition in the midst of other activities requiring undivided attention.

Technically, present power industry mobile radio systems provide voice paths controlled by the human elements at the ends of the radio circuit and the exchange of information is slow. A calling party has no way to determine the status of the called party, or whether or not his call has reached the called party's radio equipment.

An overview of mobile radio use in the power industry today concerns the two major business charters, i.e. transmission and distribution. The former requires a line of radio coverage along a narrow right-of-way which could extend from tens to hundreds of miles; the latter requires area coverage, such as a city or county. Both are usually configured for dispatch control, and are broken into segments or sectors for convenience. Long distance and large area applications usually have separate dispatcher control points for the different

segments or sectors, based upon normal work load and number of field units assigned. Work orders are relayed to the mobile work crews by the dispatcher, and the crews report their completion. Crews are alerted, and directed to emergency situations. Requests for assistance or special equipment are relayed by the dispatcher to and for the crews. Assuming that a member of the mobile work crew is within hearing of the vehicular radio, all of the functions necessary to direct the timely efforts of the crew are made available via the dispatch mobile radio system.

Peripheral uses involve on-site coordination activities where crew members are separated by distances preventing direct voice communications. The personal portable type of mobile radio is widely used for this purpose. Crews engaged in a cooperative work effort, but separated by distances too great for the low power personal portable radio, utilize the higher powered vehicular radios. Each of these applications of the mobile radio is usually accommodated by a separate radio channel assignment, thereby keeping the channel monitored by the dispatcher free of transmissions that are not directed to his attention.

Meaningful statistical data concerning mobile radio traffic of the power industry is not generally available. Therefore, the effectiveness of this communications medium is judged solely by reference to increasing requests for radio channels and the demand for radio equipment. Since these are significant indicators, it can be said that mobile radio communications are vital to the power industry, even in the elementary dispatch control configuration used principally today.

G. Trends

Mobile radio has proven itself to be a highly reliable and versatile means of communications. Its use will increase in the future, keeping pace with other expanding technologies. Several categories of trends are considered to reflect the progress of the mobile radio industry's growth.

1. Equipment

Mobile radios have undergone a number of evolutionary changes in the past decade. Tube type equipment with its bulk and power-hungry circuitry was the rule until the transistor entered the mobile radio scene in the latter half of the 1960's. The first advances in solid-state technology saw major equipment manufacturers offering a hybrid tube and transistor mobile radio. Early developments produced transistorized audio and IF amplifier stages with the vacuum tube in the RF amplifier stages and mixers. The radio frequency operating parameters of transistors could not equal those of the tube. Transmitter power amplifier stages above about 10 watts still required vacuum

tubes with attendant high voltage power supplies. Eventually the industry produced all solid state equipment using the Junction Field Effect Transistor (J-FET) and currently the insulated-gate Metal Oxide Semiconductor Field Effect Transistor (MOS-FET) whose radio frequency performance equals or exceeds the vacuum tube. High power VHF and UHF silicon transistors gradually gave rise to fully solid-state mobile radio equipment operating in the 100 watt range. By 1970 a reliable and compact fully solid state high power VHF transceiver had been announced by industry.

Frequency modulation (FM) had been established as the preferred modulation scheme for land mobile radio systems. Only a few special applications, such as aircraft, continue to use amplitude modulation (AM) equipment for VHF mobile communications. FM provides markedly superior performance over AM. The theoretical properties of FM and other forms of modulation will be covered in the Systems Engineering section of this Bulletin.

The trend in modern mobile radio equipment design is towards improved reliability, better operating characteristics and reduced packaging size. The average 100 watt solid-state VHF-FM mobile transceiver today occupies less than one cubic foot of space and requires no special power supplies, as it can be powered directly from a 12 volt DC source such as an automotive storage battery. Vehicular equipment and its base station counterparts are fully solid state up to the 100 watt power level. Higher powers can be achieved by the addition of an efficient forced air or conduction cooled ceramic tetrode amplifier. When required and authorized, power amplifier levels of up to 1,000 watts (in the VHF and UHF bands) are available. Transmitter power is controlled by FCC Rules and Regulations in accordance with the class of user license and coverage area. Evolutionary techniques are being developed to increase mobile coverage performance while reducing transmitter power. These will be described in the System Engineering section of this Bulletin.

Today's equipment is almost entirely modular in construction. Common industry practice is to design an entire receiver onto a single printed circuit board or group of small plug-in printed circuit modules - a technique developed by the computer industry. Solid-state modular construction increases equipment reliability and reduces costly maintenance time.

Equipment improvements also have taken place in the design of personal portable two-way radios. Today's personal portable radios are fully solid state, ultra-compact and produce VHF or UHF power outputs of from 100 milliwatts (0.1 watt) to about 5 watts. These units are generally operated from internal

nickel cadmium (Ni-Cad) battery packs which are rechargeable hundreds of times. Personal portable equipment can be supplied equipped with from one to twelve channels. The antenna system is either a self-contained telescoping whip or a short flexible stub-type antenna. The operating range of a personal portable is anywhere from 1 to 15 miles, depending on the band in use, the power level and the local terrain. For the mobile radio system designer these units offer most of the advantages of a vehicular two-way radio, but with a lesser transmitting range. The portability of the personal units allows them to be carried virtually anywhere by the user. Personal radio systems planning requires special engineering considerations, which are described in Section II, Systems Engineering, of this Bulletin.

2. System Design

Until the 1960's, the mobile radio system engineer was primarily concerned with the relatively mundane task of siting a radio base station, linking the base station radio equipment with a remote control point (usually via a telephone landline) and having the vehicular radios installed for the customer.

Today the mobile radio system engineer must be able to design systems which reflect the client's requirements in an increasingly difficult environment.

The principal trends in mobile radio system design are:

- Greater use of hand-carried portable radios rather than vehicle-mounted radios
- Greater utilization by multiple users of the relatively few "ideal" base station sites (antenna farms) in each population center
- Increasing use of data transmission equipment and computer technology
- Coverage of large service areas by two or more simultaneous co-channel transmitters (simulcast)
- Use of the new 800 MHz band

Each of these trends is discussed below.

a. Portable Radio Systems

Today, a large number of mobile radio systems are utilizing hand-carried portable radios rather than vehicle-mounted radios. The portable radios provide personal communications regardless of the location of the user.

Since the portable radios have low power and inefficient antennas when compared to vehicular radios, their range is considerably less than vehicular radios. To compensate for this reduction in talk-back range it is necessary (for large service areas) to provide additional fixed receivers such that a portable radio will always be within range of at least one receiver. These "receive sites" (frequently receive-only sites) are called satellite receivers. The satellite receivers are connected to the control point via leased telephone lines or radio links. Since a portable radio signal may be picked up by two or more satellite receivers, it is necessary to provide a means of selecting the best signal from a group of incoming signals. The equipment that performs this function is called a "comparator". The comparator selects (or votes) on the best signal and blocks all others. Section II.E.5 of this Bulletin describes receiver selection systems in more detail.

b. Antenna Farms

In most populated areas there are usually only a few ideal base station sites for mobile radio systems. These could be the roofs of very tall buildings or a convenient nearby hilltop or mountain top. Frequently these sites are crowded with existing users and it is difficult to add new systems due to intermodulation interference problems, lack of equipment space, or lack of space on the tower for additional antennas. It is possible to "clean up" these crowded sites and to provide room for new users by managing the site as an "antenna farm". This concept works best when a single organization controls the site and can impose rules on the use of the site. Typical approaches in reducing intermodulation and other forms of interference include:

- Using separate, dedicated antennas for transmitters and receivers

- Providing as much vertical or horizontal separation as possible between transmit and receive antennas

- Multicoupling (or combining) as many transmitters as possible to as few antennas as possible

- Multicoupling as many receivers as possible to as few antennas as possible

- Using bandpass cavities at the output of all transmitters and at the input of all receivers

- Requiring stringent quality control on the maintenance of RF equipment

The antenna farm concept works best when the site management organization takes responsibility for all multicoupling equipment, coaxial transmission lines and antennas. The site users merely install their radio equipment in specified locations and maintain it to the standards required.

Section II.E.6.c discusses the multicoupling equipment utilized in antenna farms.

c. Data Transmission Equipment and Computers

The use of data transmission equipment and computers is revolutionizing the mobile radio industry.

Data transmission equipment is being used for many applications such as:

1. Shortening the time required to establish a path for exchange of voice messages from mobile units to dispatch location

2. Transmitting vehicle ID number, vehicle status and location messages quickly and accurately

3. Transmitting routine information as "canned messages"

4. Accessing a computer data base directly from a vehicle

5. Activating remote equipment and receiving information on the status of remote equipment

Section II.E.11 of this Bulletin describes data transmission equipment and systems in more detail.

Computers are currently used in dozens of mobile radio dispatch systems for assisting dispatchers in the allocation of field resources. These computer-aided dispatch (CAD) systems are particularly effective with public service organizations having fleets of vehicles of 100 or more. CAD systems reduce response time to calls for service and dispatcher workload. They can provide statistical information for improved management of fleet operations since almost every vehicle action is captured by the system. Section II.E.12 of this Bulletin describes CAD systems in more detail.

d. Simulcasting

In the past when a large, contiguous, mobile radio service area could not be adequately covered from a single base station location, system operators usually installed two

or more base stations whose combined coverage was adequate over the entire service area. Base-to-mobile transmissions would employ one of two techniques:

- Transmit the same message simultaneously using a different transmit frequency at each base station.
- Transmit the same message sequentially using the same transmit frequency at each base station.

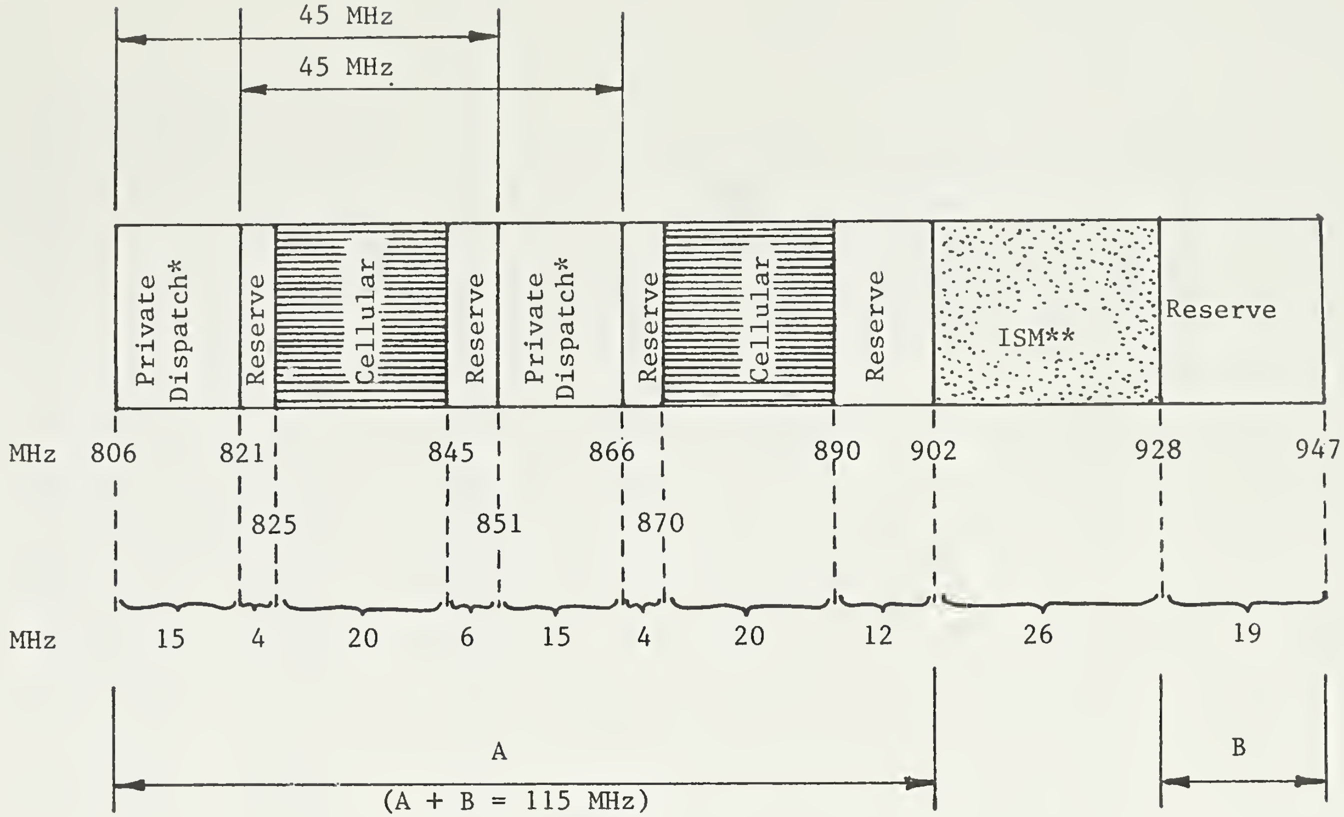
The first technique is wasteful of frequencies and requires multi-channel mobile radios, each tuned to the correct channel. The second technique is wasteful of time. System operators who attempted to transmit the same message simultaneously using the same frequency at each base station found that interference zones were created wherever coverage from two or more transmitters overlapped. Within such zones, distortion was intolerable and messages were totally garbled.

Today many techniques are available for system operators to utilize simultaneous co-channel transmission, commonly known as "simulcasting" (or "comulcasting"). These include: control of the rms carrier frequency differences, modulation delay compensation, improvement of the mobile receiver capture ratio, speech clipping, and careful antenna pattern design. Because of its complexity, this subject cannot be treated in its full depth in this Bulletin.

e. The 800 MHz Band

As a result of increasing land mobile frequency congestion during the early 1970's, in 1976 the FCC in Docket 18262 allocated 115 MHz of spectrum in the 806-947 MHz band. Figure I-1 shows how this portion of the spectrum has been allocated. This amount of spectrum represents more than three times the total spectrum previously available to land mobile radio in the history of its existence. The 115 MHz was allocated among private dispatch, cellular (or common carrier mobile telephone) systems and reserve channels for future expanded communications services.

The private dispatch spectrum was further subdivided into "conventional" and "trunked" systems. Of 600 channels set aside for private dispatch, 100 were designated for conventional systems. The remaining 500 channels include 200 channels for trunked systems and 300 channels held in reserve. The FCC believes trunked systems will provide more efficient use of the spectrum.



* Available to Power Radio Service

** Industrial, Scientific and Medical -
Not available for land mobile

Figure I-1 Allocation of 800 MHz Band Spectrum

The 800 MHz band provides an attractive alternative for power industry mobile radio users who are considering either a new system in or near a metropolitan area, or upgrading an existing system which is plagued by interference.

II. SYSTEMS ENGINEERING

A. Power Industry Mobile Radio Systems

This section of the Bulletin covers the subject of mobile radio system engineering from a description of basic mobile radio systems, through design objectives, mobile radio equipment, system design, to analytic procedures for examination of system performance. The material is arranged in a way to lead the reader in logical progression through systems engineering from system concepts to performance measurement.

1. Basic Mobile Radio Systems

Mobile radio systems are usually classified by defining:

- The frequency band utilized:
  - VHF low band
  - VHF high band
  - UHF low band
  - UHF high band
  - 800 MHz
- The type of radio channel:
  - Simplex
  - Duplex
- The type of control system:
  - Local control
  - Remote control

The following discussion of basic mobile radio systems will focus on the above-listed characteristics.

a. Frequency Band

In the Power Radio Service there are five frequency bands authorized for mobile radio systems. Figure II-1 lists these bands together with the pertinent technical standards associated with each band.

Each frequency band has different characteristics and is subject to FCC rules which limit its operational capabilities. Figure II-2(a) lists the principal characteristics and limitations of each band, and Figure II-2(b) compares the ranges obtained in each band.

Band (MHz)	Common Designator	Applicable FCC Rules	Frequency Stability (%)				Auth. Bandwidth kHz	Freq. Deviation kHz	Max. Power watts		Chan. Spacing kHz	T/R Sep MHz
			Fixed		Mobile							
			>300W	<300W	>3W	< 3W			PIP	ERP		
27.235 - 48.54	VHF Low Band	91.254	.002	.002	.002	.005	20	5	500		20	-
153.410 - 173.39625	VHF High Band	91.254	.0005	.0005	.0005	.005	20	5	600		15	-
451.025 - 467.525	UHF Low Band	91.254	.00025	.00025	.0005	.0005	20	5	600		25	5
471.3125 - 510.4125	UHF High Band	91.114	.00025	.00025	.0005	.0005	20	5		1000	25	3
806.0125 - 866.0	800 MHz Band	89.601	.00015	.00015	.00025	.00025	20	5	2000		25	45

Notes:

1. This table summarizes the mobile frequency bands and technical standards in the Power Radio Service. For exceptions, limitations, and clarifications, refer to the applicable FCC Rules and Regulations.

2. The bands listed in this table may include Operational Fixed (Point-to-Point) frequencies.

Figure II-1 Power Radio Service Mobile Frequency Bands

	Frequency Band (MHz)			
	30-50	150-170	450-512	806-866
General Use	Rural	Suburban	Suburban & City	City
Terrain/Bldg. Losses	Lowest	Medium	High	Highest
Penetration into Buildings	Worst	Average	Good	Best
Foliage Losses	Lowest	Medium	High	Highest
Transmission Line Losses	Lowest	Average	High	Highest
Multi-Path Effect	Barely Noticeable	Noticeable	Pronounced	Very Pronounced
Skip Interference	Frequent	Some	None	None
Ambient Noise Level	High	Medium	Low	Lowest
Availability of Channels	Improving	Poor	Congestion in Cities	Good
Relative Cost of Equipment	Low	Medium	High	Highest
Mobile Antenna Size	Largest	Average	Small	Smallest
Base Antenna Gain	Lowest	Average	High	Highest
Mobile Relay Operation	Not Permitted*	Not Permitted*	Permitted	Permitted

* In Power Radio Service

Figure II-2(a) Characteristics of Mobile Radio Frequency Bands

	Frequency Band (MHz)			
	30-50	150-170	450-513	806-866
Range (miles)				
Base to Mobile	70	40	30	20
Mobile to Base	50	30	20	15
Mobile to Mobile	40	10	7	5
Assumptions				
Height* of Base Antenna (ft)	100	100	100	100
Base Station Power (watts)	330	300	200	125
Base Antenna Gain (dBd)	0	3	9	12
Mobile Power (watts)	100	80	15	15
Mobile Antenna Gain (dBg)	0	0	0	0
Effective Rcvr.Sensitivity (μV)	2.0	1.5	1.0	0.5

NOTE: Ranges shown are approximate and do not take into consideration terrain, building and foliage losses or high ambient noise environments.

*above smooth earth

Figure II-2(b) Typical Ranges Obtained in the Mobile Radio Frequency Bands

b. Types of Radio Channels

Radio channels in mobile radio systems are designated as either simplex (single frequency) or duplex (two frequencies). Figure II-3 illustrates a simplex channel and the three principal types of duplex channels.

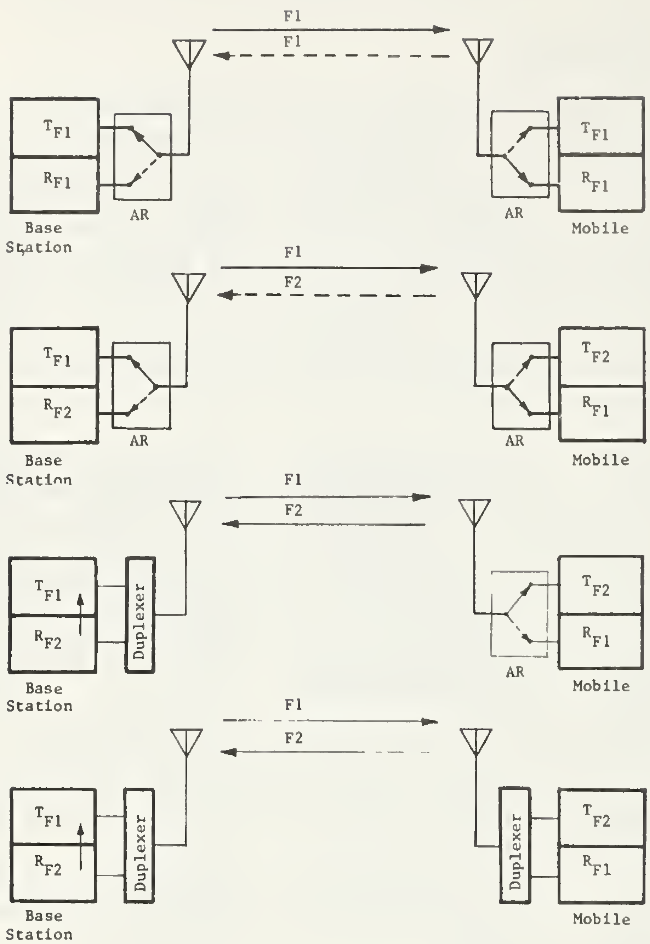
1. Simplex Channels

Simplex channels employ the same frequency, F1, for each direction of transmission. Transmission and reception take place sequentially, in one direction at a time. When the radio station's push to talk (PTT) switch is depressed, the antenna relay connects the transmitter section to the antenna and disconnects the receiver section from the antenna. Since a single frequency is employed, transmissions are on a "party line" basis, and any radio can listen and talk to any other radio within range.

Most mobile radio systems have their base stations situated on a high point and utilize relatively high RF power output and antenna gain with respect to a mobile station. Consequently, the talk out range of the base station is usually greater than the talk back range of the mobile station. In simplex systems this inequality in range can create problems. Figure II-4 illustrates typical problems.

- Base can talk out to Mobile 1 and Mobile 2. Mobile 1 can talk back to Base but Mobile 2 cannot. (In this illustration Base cannot talk out to Mobile 3 or Mobile 4.)
- Mobile 1 and 3 can talk to each other but not to Mobiles 2 and 4.

A frequent problem in simplex systems is one mobile station inadvertently "covering" another. Figure II-5 illustrates how this happens: Mobile 1 is talking to Base from distance x. Mobile 2 is sufficiently far from Mobile 1 to be out of mobile-to-mobile range but is closer to base (distance y) than Mobile 1. Mobile 2 transmits to Base assuming no one is "on the air" and is sufficiently close to Base to transmit a signal which is at least 6 dB stronger than the Mobile 1 signal. The signal from Mobile 2 is sufficiently stronger to "capture" the Base Station receiver and completely override the Mobile 1 signal.



SIMPLEX

F1 in both directions, one at a time.

HALF-DUPLEX

F1 in one direction, F2 in other direction, one at a time. F2 not retransmitted on F1 by base station. (Not commonly used)

DUPLEX PTT

F1 in one direction, F2 in other direction. Mobile transmissions on F2 retransmitted on F1 by base station. Mobile operates on PTT basis. (Typical mobile relay system) $|F1 - F2| > 200$ kHz

FULL DUPLEX

F1 in one direction, F2 in other direction. Mobile transmissions on F2 retransmitted on F1 by base station. Mobile station can transmit while listening but does not retransmit base station transmissions. (Typical mobile telephone system) $|F1 - F2| > 200$ kHz

Legend

AR = Antenna Relay
T = Transmitter
R = Receiver
F = Frequency

Figure II-3 Simplex and Duplex Radio Channels

R_{BM} = Talk out range of base station

R_{MB} = Talk back range of mobiles

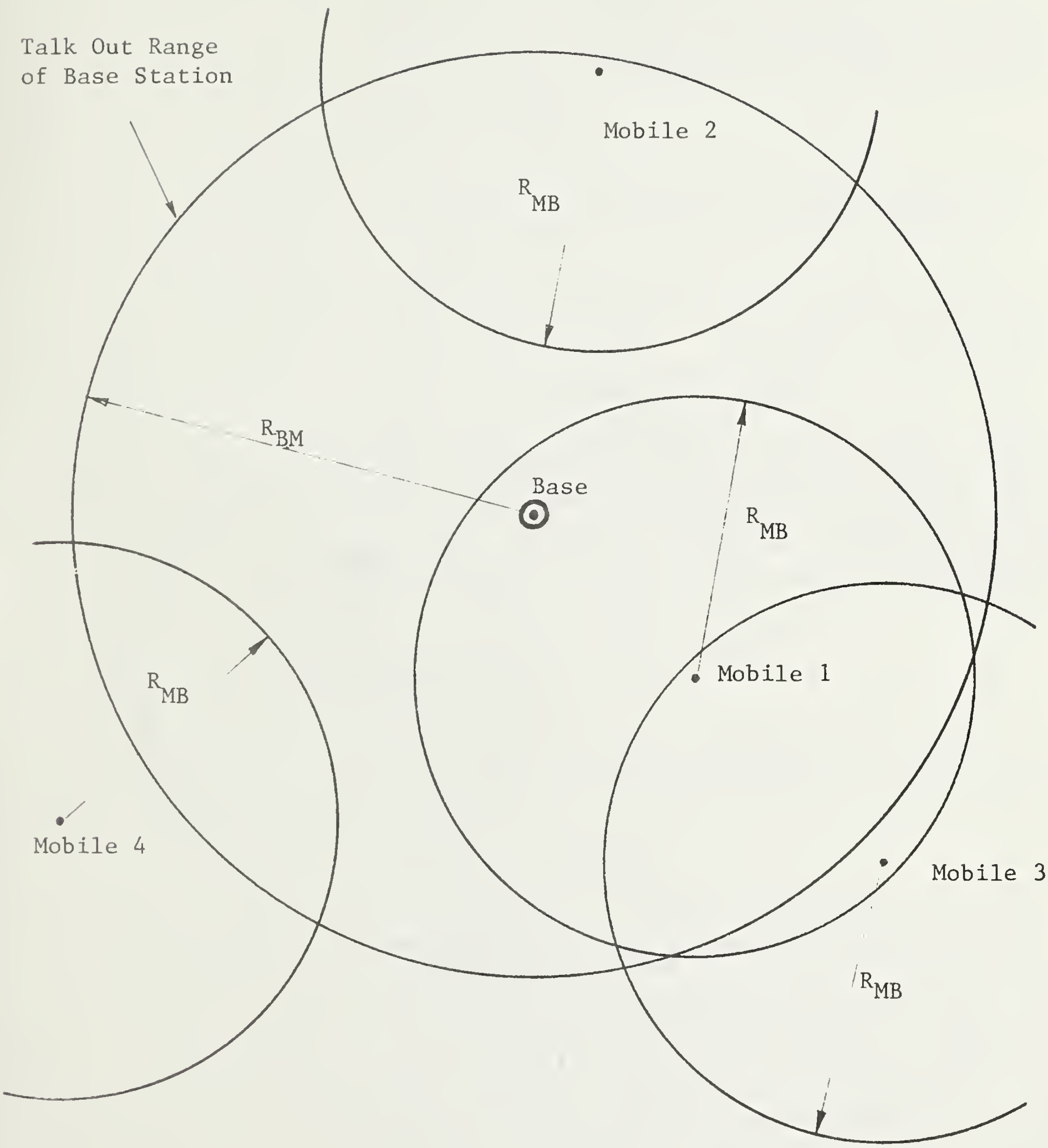


Figure II-4 Talk-out vs. Talk-back Range Problem in Simplex Systems

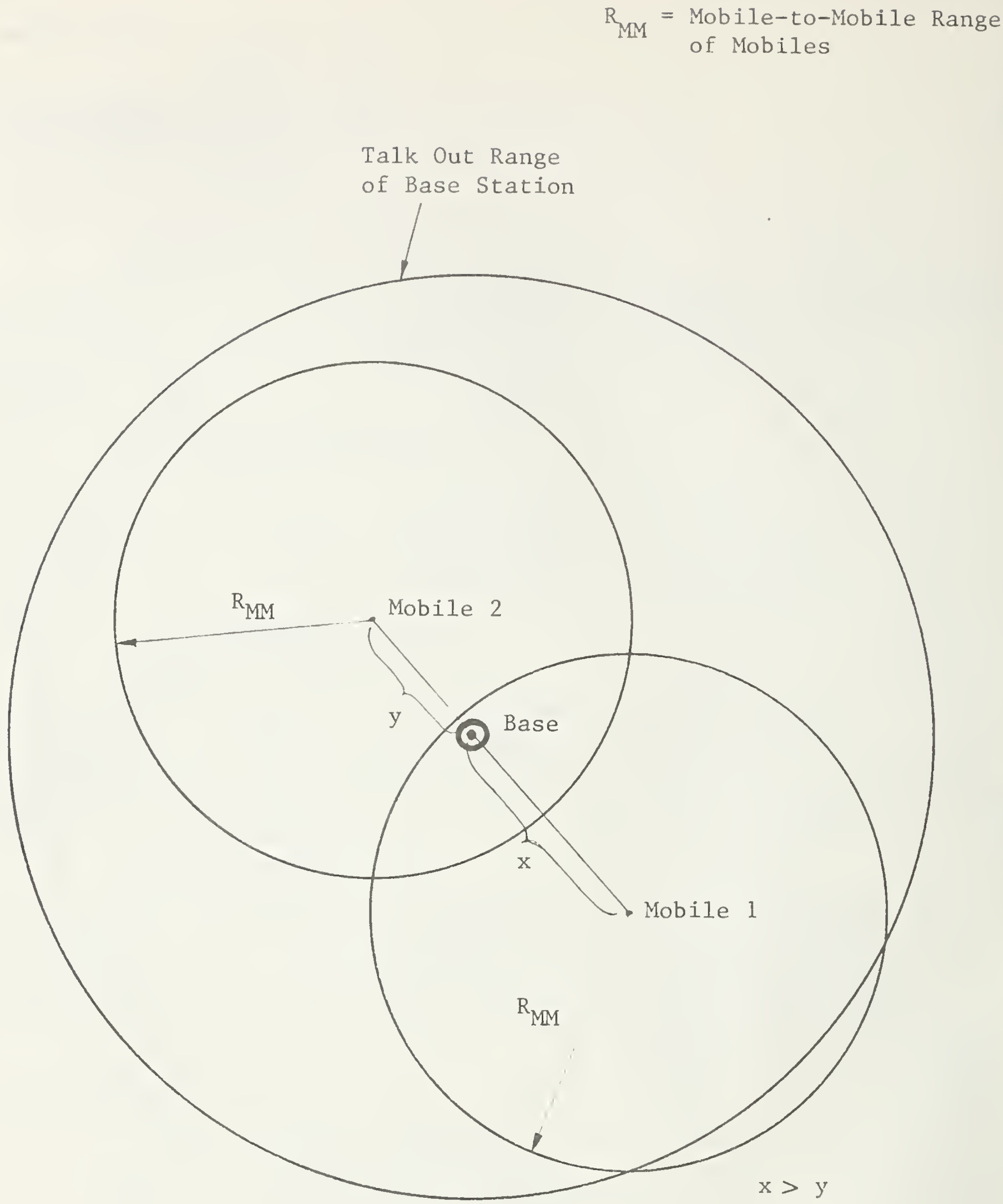


Figure II-5 Inadvertent "Covering" of One Mobile by Another in Simplex Systems

2. Duplex Channels

Duplex radio channels employ two frequencies per channel, F1 and F2; one frequency for each direction of transmission. Duplex systems have the following advantages over simplex systems:

- More efficient utilization of the radio frequency spectrum. Two duplex base stations using the same pair of frequencies can be spaced closer together than two simplex base stations using the same frequency.

- Duplex base stations can be configured as mobile relay (repeater) stations, providing greater mobile-to-mobile range than simplex systems.

- Mobile stations anywhere within the talk out coverage area of a mobile relay station can monitor all channel activity. Inadvertent "covering" of one mobile by another is thus avoided.

A variety of configurations is possible with duplex systems. Many names have been applied to the different variations, and the land mobile industry has not standardized on terminology. For convenience and consistency in this Bulletin, the following terms will be used to define the principal types of duplex systems:

- Half-duplex
- Duplex PTT
- Full-duplex

Each of these systems is illustrated in Figure II-3 and described below.

a. Half-Duplex Systems

As illustrated in Figure II-3, the base station transmits on F1 and receives on F2; the mobile stations transmit on F2 and receive on F1. Both base station and mobile stations are equipped with antenna relays. The mobile transmit frequency, F2, is not retransmitted on F1, the base station transmit frequency. The principal disadvantage of this type of duplex system is that the mobile stations can only receive the transmissions of the base station and cannot receive the transmissions of other mobiles in the system. This type of channel is rarely used except for applications where chatter between mobiles is undesired.

b. Duplex PTT Systems

As illustrated in Figure II-3, the base station transmits on F1 and receives on F2; the mobile stations transmit on F2 and receive on F1. The base station is equipped with a duplexer and the mobile station with an antenna relay. The base station is arranged to automatically and simultaneously retransmit on F1 any signal originated by mobile stations on F2. When a base station is equipped to perform this function, it is called a mobile relay (or repeater) station. In the Power Radio Service mobile relay operation is permitted only on frequencies above 450 MHz.

This type of system is widely used for dispatch operations in the land mobile radio services due to its superior mobile-to-mobile communications capability and the many advantages over simplex systems.

A separation of 200 KHz or more is required between F1 and F2 for efficient operation of the duplexer at the base station. Frequency separations between F1 and F2 in the bands authorized for mobile relay operation in the Power Radio Service are:

Band	Separation (MHz)
450-470 MHz	5
470-512 MHz	3
800 MHz	45

Direct mobile-to-mobile communication with this type of system is not possible unless the mobile stations are equipped with a wide-spaced transmitter.* The wide-spaced transmitter allows F1 to be incorporated as a mobile transmit frequency (usually on another channel position). With this capability the mobiles can communicate with each other directly in a simplex mode on F1. This capability is often referred to as "talk around the repeater".

---

* Standard mobile radios have a maximum allowable frequency spread of ±0.2% from center frequency for no deterioration of specified performance. This is approximately ±1.0 MHz in the UHF (450-512 MHz) bands. UHF Mobile radios can be ordered with 5.5 MHz or more allowable frequency spread.

c. Full-Duplex Systems

As illustrated in Figure II-3, the base station transmits on F1 and receives on F2; the mobile stations transmit on F2 and receive on F1. The base station and mobile stations are equipped with duplexers to permit simultaneous transmission and reception. The base station is arranged to simultaneously retransmit on F1 any signal originated by mobile stations on F2. The mobile stations can transmit on F2 while listening on F1 but do not retransmit base station transmissions.

Full-duplex channels are normally used in mobile telephone systems (MTS and IMTS). However, the additional cost of the mobile duplexer usually precludes its use in normal public safety, industrial or land transportation mobile radio dispatch systems.

Normally a separation of 3 MHz or more is required between F1 and F2 for efficient operation of the mobile duplexer.

Direct mobile-to-mobile communication with this type of system is not possible unless the mobile radios are equipped with wide-spaced transmitters. In mobile telephone systems this capability is not provided.

c. Types of Control Systems

Mobile radio systems can be either locally or remotely controlled. Local control means that the equipment controlling the operation of a base station (e.g. power on/off, push to talk, channel selector, squelch and volume controls) are installed as part of, or immediately adjacent to (within approximately 100 feet), the base station.

Remote control means that the equipment controlling the operation of a base station is from hundreds of feet to many miles away from the base station. Remote control systems can utilize either physical (wireline) or radio control links. If the physical remote control link is a metallic pair of lines, the remote control system can utilize DC signaling. If the remote control link does not provide DC continuity, tone signaling must be used. A discussion of DC and tone remote control systems is included in Section II.E.9 of this Bulletin.

d. Typical Basic Mobile Radio System Configurations

There are several typical basic mobile radio system configurations. The principal variants are the type of radio channel used (simplex or duplex) and the type of control system used (local or remote). The most common basic mobile radio system configurations are listed below and are illustrated in Figures II-6 through II-11:

- Local Control, Simplex (Fig. II-6)
- Physical Remote Control, Simplex (Fig. II-7)
- Radio Remote Control, Simplex (Fig. II-8)
- Physical Remote Control, Duplex (Fig. II-9)
- Radio Remote Control, Duplex (Fig. II-10 and II-11)

There are many variations of all the basic systems. Special configurations are fairly common because of the great flexibility provided by the use of radio remote control, special antenna designs, tone coded systems and the availability of four mobile radio bands.

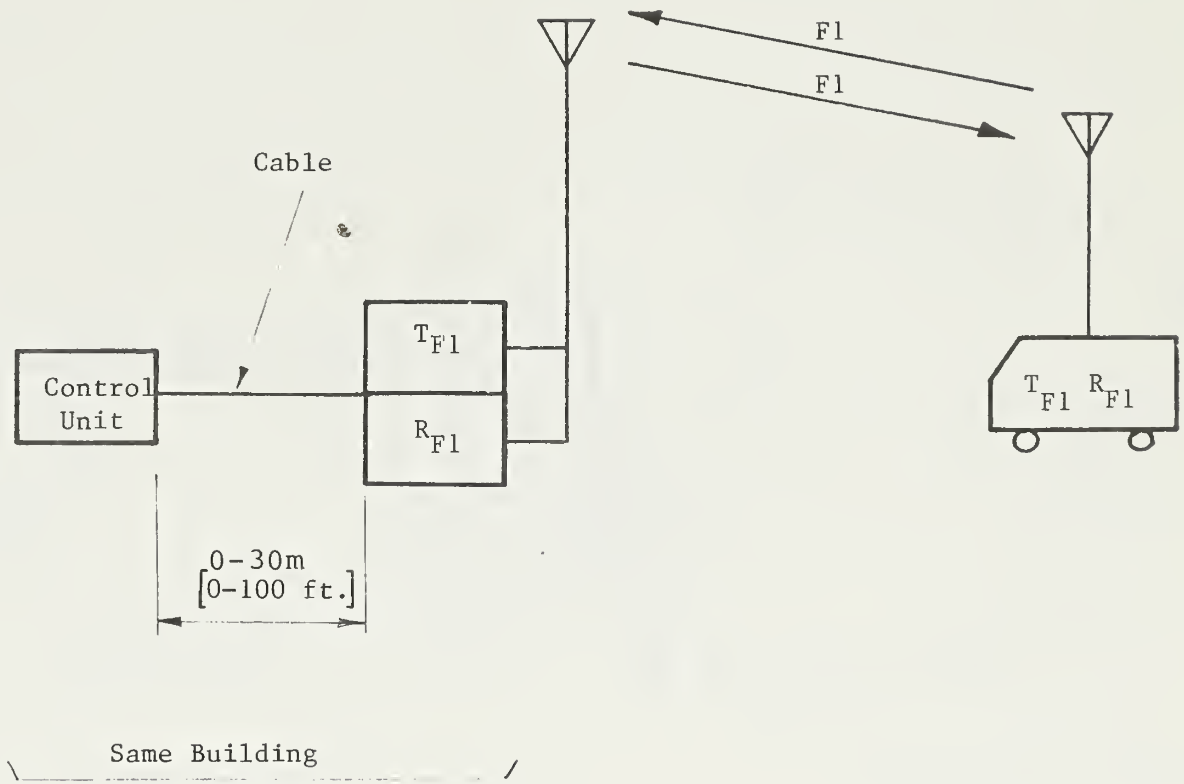


Figure II-6   Local Control, Simplex, Mobile Radio System

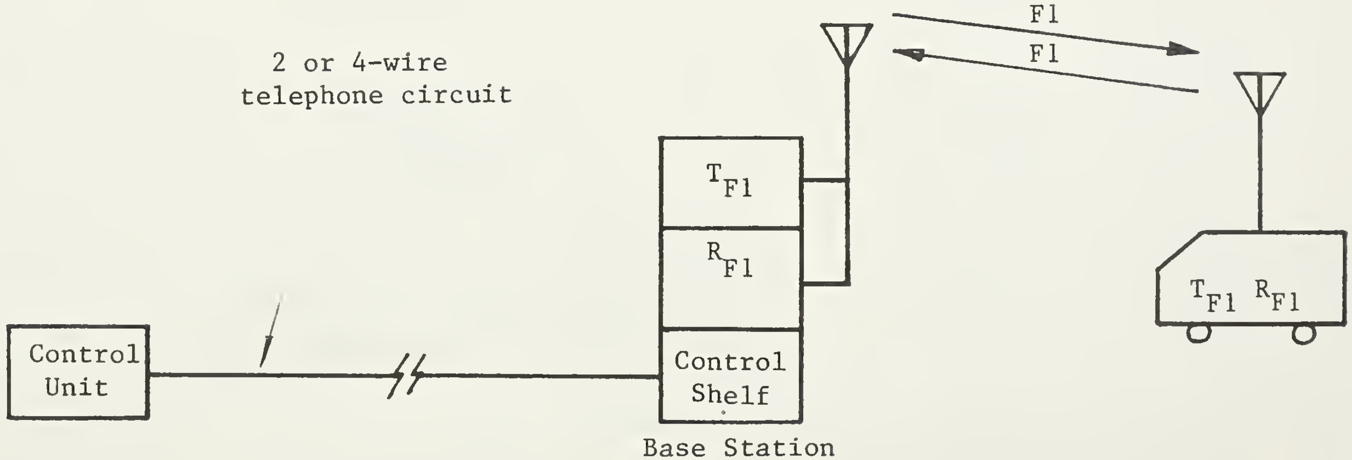
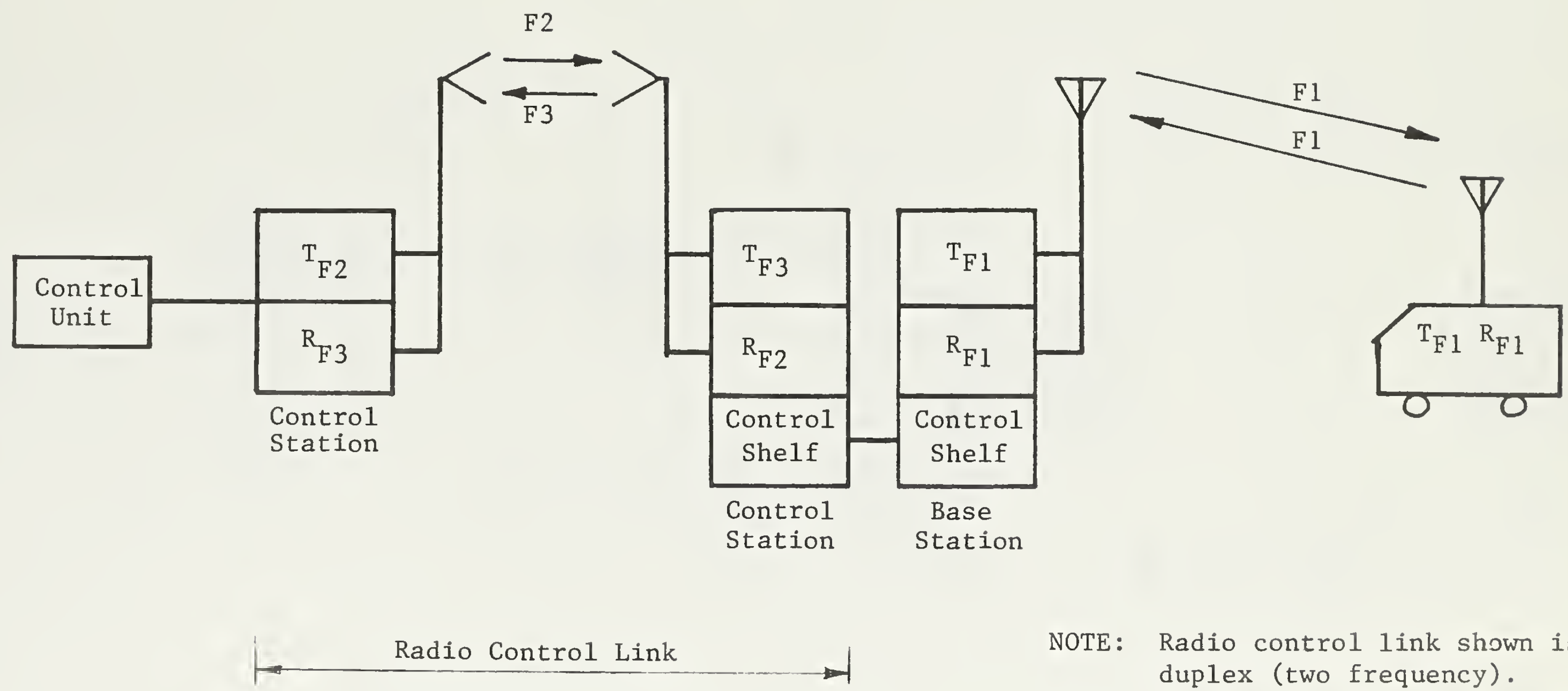


Figure II-7 Physical Remote Control, Simplex, Mobile Radio System



NOTE: Radio control link shown is duplex (two frequency). Simplex link is also possible.

Figure II-8 Radio Remote Control, Simplex, Mobile Radio System

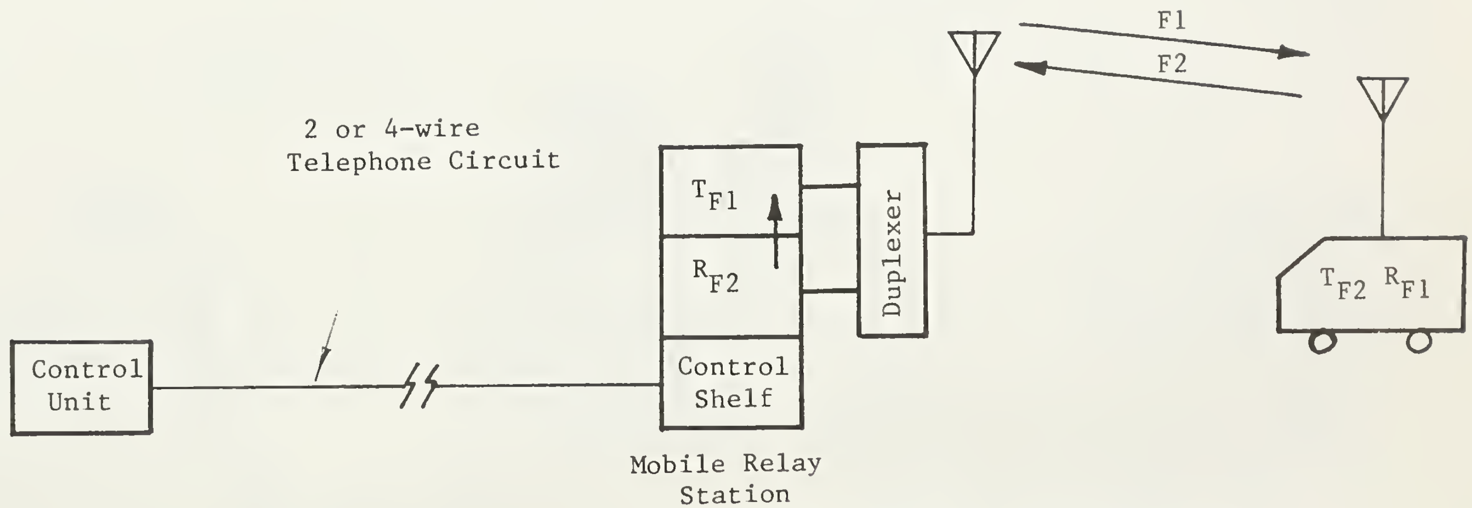


Figure II-9 Physical Remote Control, Duplex, Mobile Radio System

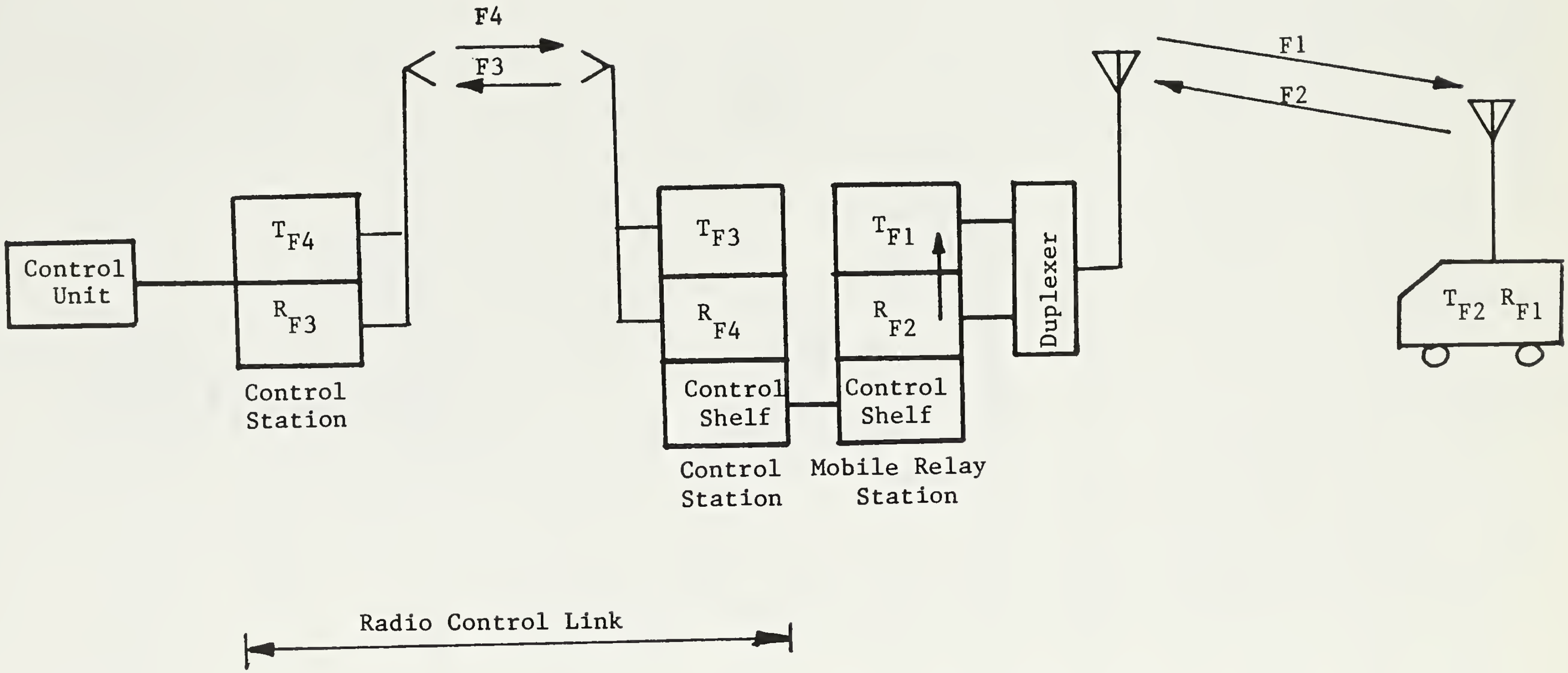


Figure II-10 Radio Remote Control, Duplex, Mobile Radio System

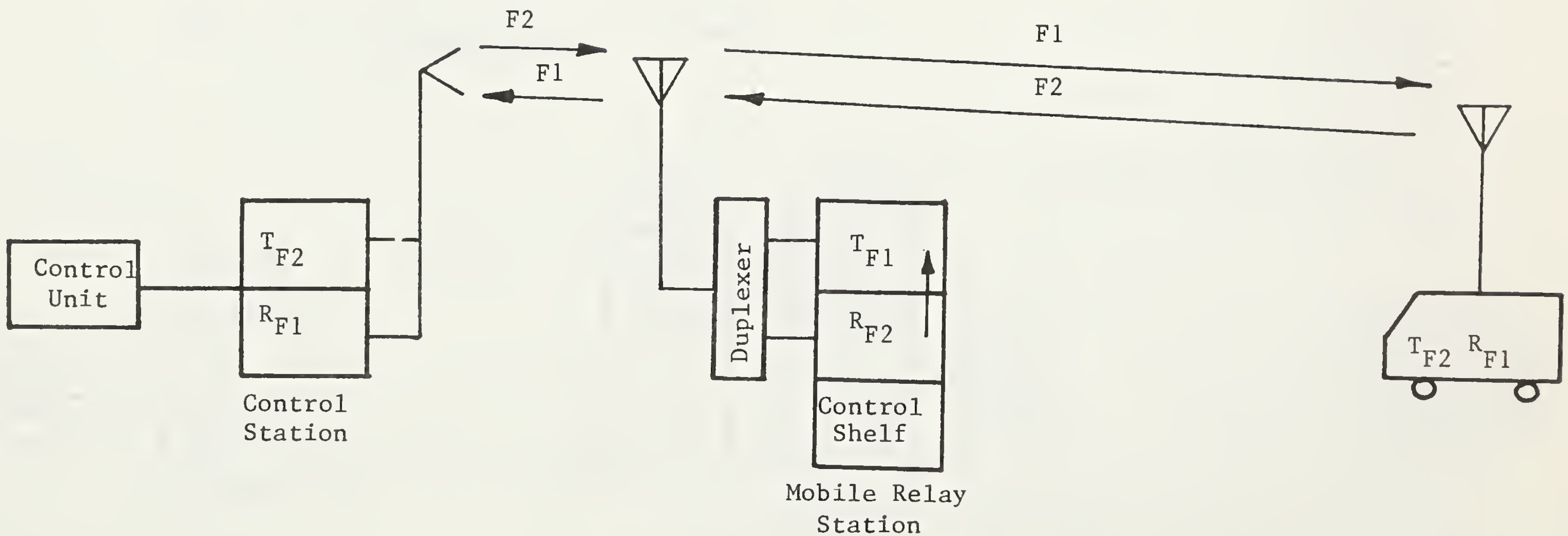


Figure II-11 Radio Remote Control, Duplex, Mobile Radio System

2. System Examples

Section II.A.1 described typical basic mobile radio systems. While these basic systems may be adequate in many instances, expanded capabilities are often essential in real-life situations. This section presents the following examples of "engineered" mobile radio systems commonly found in the power industry:

- System A: City or county coverage with a single radio remote controlled mobile relay (repeater) station
- System B: Large area coverage with two mobile relay stations
- System C: City or county coverage using satellite receivers and a mobile relay station
- System D: "Strip" coverage (along power line right-of-way) using a backbone system and sector coverage by mobile relay stations

Each of these examples is discussed and illustrated.

a. System A

Mobile Radio System A is illustrated in Figure II-12. This type of system is generally used to provide coverage to a square or circular service area.

The system consists of a mobile relay (repeater) station located approximately in the center of the service area. The mobile relay station is controlled by means of a control station located at the dispatch location. Each mobile is equipped with two channels: one, a duplex channel, for use with the mobile relay station and the other, a simplex channel, for direct car-to-car communications. The control station is equipped with a second transmitter (or a two-frequency transmitter) which allows direct simplex communication with mobiles on F1 in the event of failure of the mobile relay station.

In order to activate the mobile relay station, the system operates with tone-coded squelch (CTCSS). Refer to Section II.E.10.a for a description of CTCSS.

The control station is equipped with a tone encoder for control of essential mobile relay station functions such as CTCSS disable (for monitoring) and repeater disable (for system discipline and dispatcher priority override).

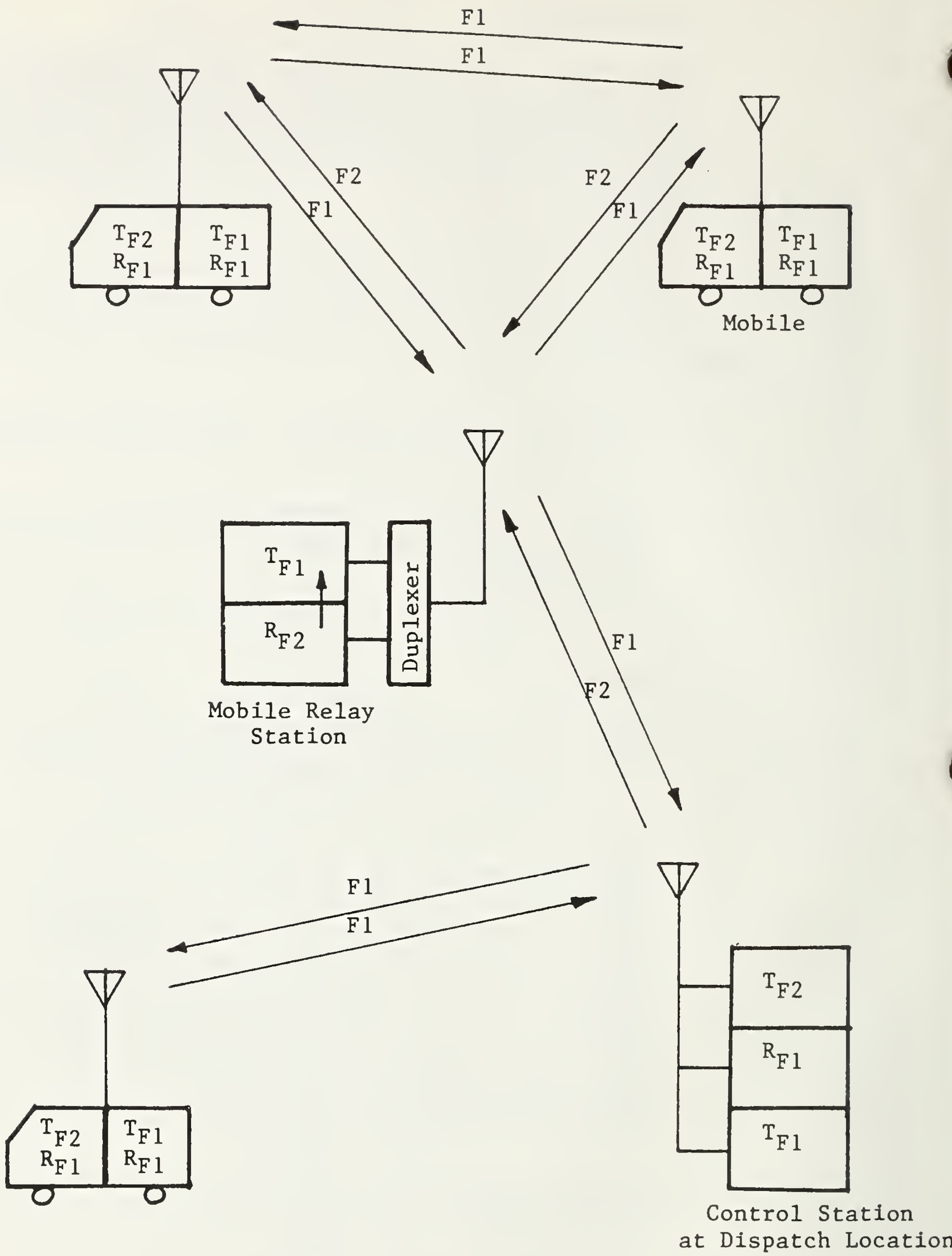


Figure II-12 Mobile Radio System A

b. System B

Mobile Radio System B is illustrated in Figure II-13. This type of system is generally used for large service areas where a single base station location cannot adequately provide coverage.

The system consists of two mobile relay (repeater) stations, one for each sector of the service area, and located approximately in the center of their service sector. The mobile relay stations operate on different duplex channels and each is controlled by a separate control station. Each mobile is equipped with three channels: one duplex channel for Sector 1, one duplex channel for Sector 2 and one simplex channel for direct car-to-car communications. One of the control stations is equipped with a second transmitter (or a two-frequency transmitter) which allows direct simplex communications with mobiles on F1 in the event of failure of one or the other mobile relay station.

As in System A, System B must use tone coded squelch and tone remote control of the mobile relay stations.

c. System C

Mobile Radio System C is illustrated in Figure II-14. This type of system is generally used to provide coverage to portable radios in a city environment.

The system consists of satellite receivers scattered throughout the service area and a mobile relay station in the center of the service area.

The signals from the portable radio are received by one or more of the satellite receivers and are then compared for strength and/or quality at the comparator. The best signal is then routed to the base transmitter for rebroadcasting and to the control unit. Section II.E.5 of this Bulletin describes this type of system in more detail.

System C must use tone-coded squelch.

d. System D

Mobile radio system D is illustrated in Figure II-15. This type of system is used to provide extended communications for "strip" (or "ribbon") type of coverage such as required for highways, railways, pipelines or power industry transmission line right-of-way.

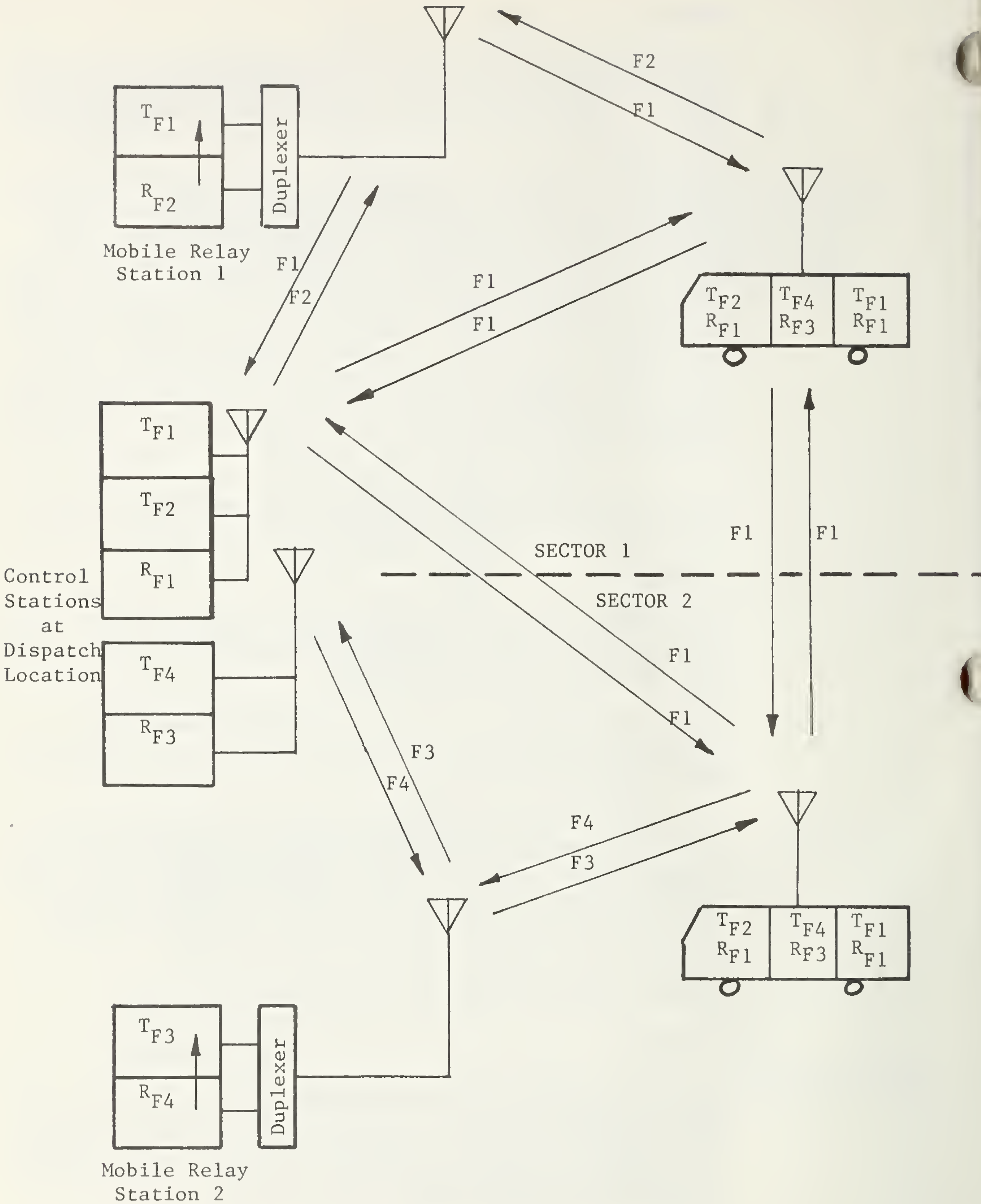


Figure II-13 Mobile Radio System B

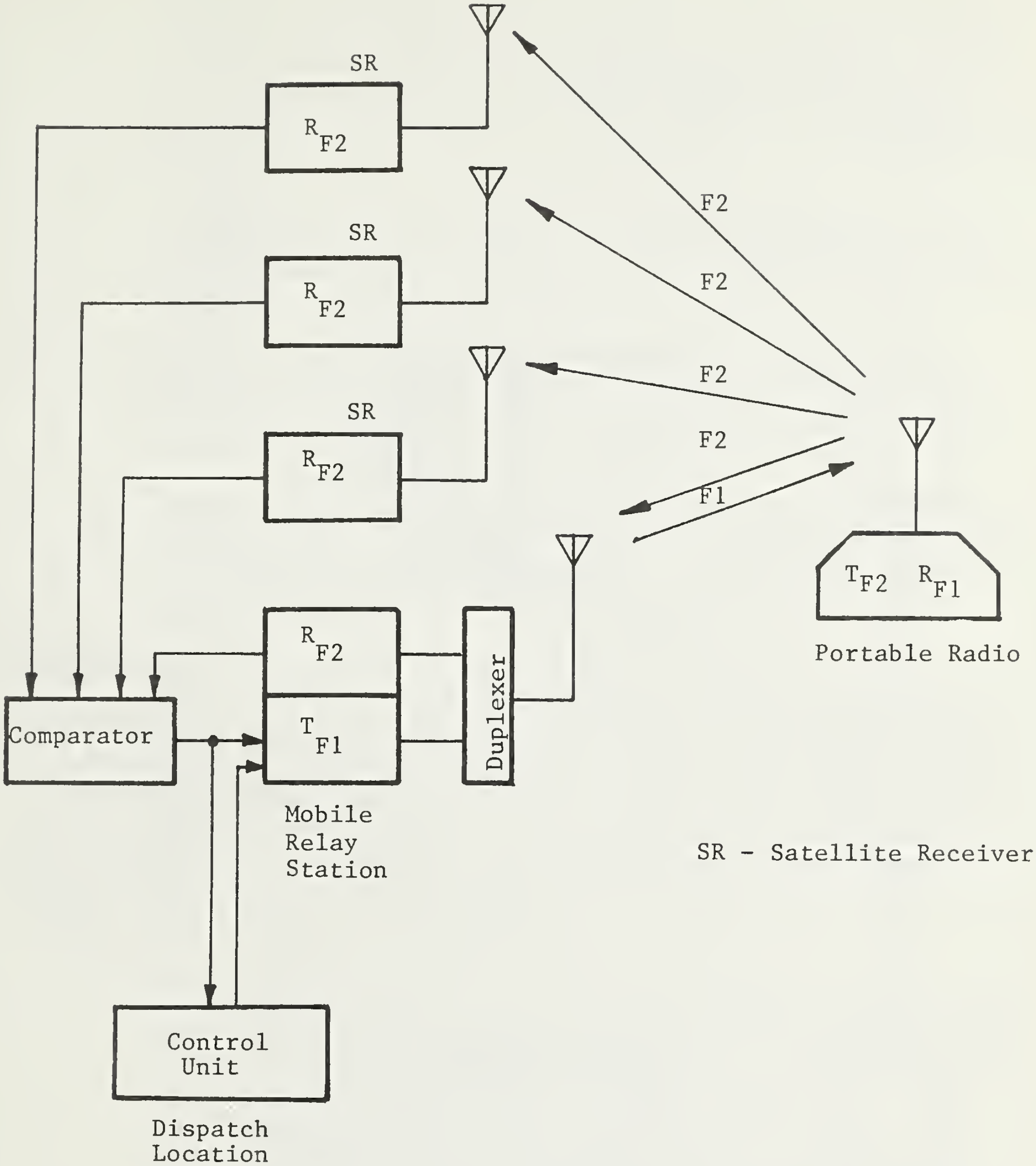


Figure II-14 Mobile Radio System C

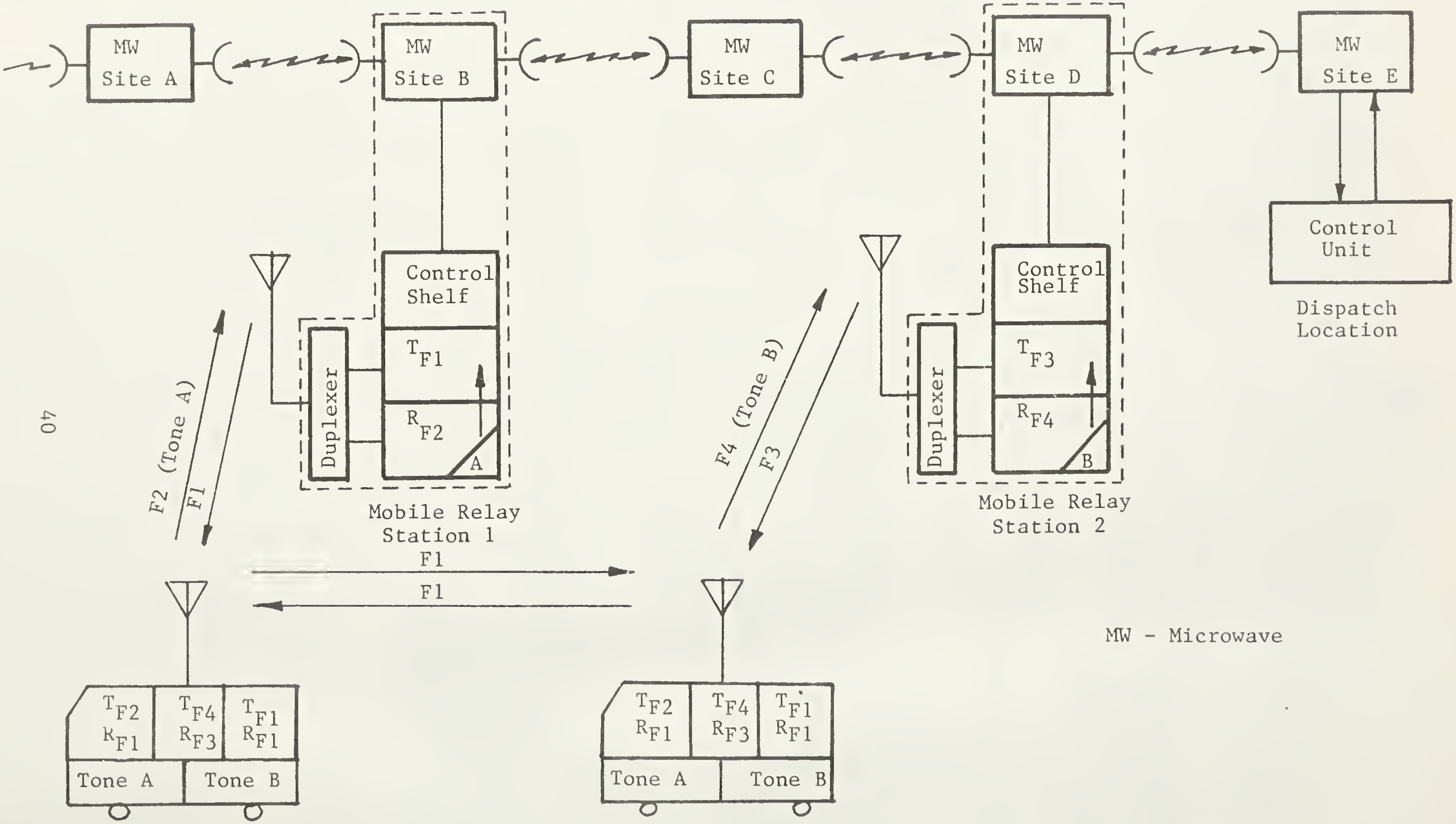


Figure II-15 Mobile Radio System D

Most strip coverage mobile radio systems usually include a backbone transmission system such as a microwave relay or a coaxial cable system which parallels the right-of-way and provides the necessary control circuits.* Mobile relay stations are installed at various microwave sites such that overlapping sector coverage is provided to mobiles operating along the right-of-way.

All mobile relay stations can operate on the same duplex frequency pair, but to reduce overlap interference it is desirable to use two duplex frequency pairs, in order that adjacent stations use alternate pairs.

Usually the control point is connected to all the mobile relay stations with a common 4-wire party-line control circuit. (In some systems two or more party line control circuits are provided.)

A tone-coded squelch system using several tones is usually used to reduce the probability that a mobile station will activate two or more mobile relay stations simultaneously. A specific tone code is assigned for each mobile relay station.

Each mobile is equipped with three channels: the two duplex channels for use with the mobile relay stations and a simplex channel for direct car-to-car communication. Each mobile is also equipped with a tone-coded squelch selector so that the mobile operator can select the proper tone code for the mobile relay station closest to his location. It is often desirable to equip mobiles with channel scanning receivers so that no messages are missed if the radio is tuned to the wrong channel.

With this type of mobile radio system, DTMF signaling together with microprocessor-controlled mobile relay stations and microprocessor-controlled mobile control heads can add great flexibility and ease of operation. The DTMF signaling can be used to access individual repeaters, to call other mobiles individually, and to call land telephones. The microprocessors can be used to search for idle radio and backbone channels, to set up mobile-to-mobile, mobile-to-dispatcher and mobile-to-land telephone connections.

Bidirectional base station antennas are particularly effective with this type of system. Refer to Section II.E.6.a.2.

---

* The backbone control circuits can also be provided by common carrier leased circuits.

B. Systems Considerations

Two types of Borrower's need exist in the power industry for mobile radio systems. The first, and rarely encountered type, is for the organization which has no mobile radio service in operation. The second type is for the organization that has been using mobile radio for some time. For either type of need the Borrower must consider the same factors in the decision process leading to a mobile radio system commitment. Often it is the organization with mobile radio experience that finds these factors most difficult.

Mobile radio system technology has advanced so rapidly since the late 1960's that Borrower's operation's activities not previously considered for mobile radio application are now feasible. For the organization obtaining its first mobile radio system, advantage can be taken of these advances in an orderly, time-phased fashion. Systems application planning and the procurement of hardware representing logical building block integration of the user's operation's functions can be readily accomplished. The experienced power industry mobile radio user who needs expanded service finds his considerations more complex. This organization has an investment of functioning equipment representing a communications concept that is based upon one person (a dispatcher) directing or reporting elementary human movement activities. When adding to this inventory it is normal to consider equipment that continues this concept. The advances represented by today's mobile radio system technology should be included in procurements for expanded mobile radio service. How to achieve this with sound economic planning makes systems considerations an important mobile radio subject. Essentially these considerations are of an applications nature, containing a minimum of technical matter, and relate to the decision process that provides a modern, viable, and cost-effective mobile radio capability.

Topics requiring thought and planning before addressing technical/implementation matters are reviewed in the following paragraphs and are represented by the subject titles below.

- Current purpose and use of mobile radio
- 10 and 20 year projected use of mobile radio
- Operations' routines
- Automation of Operations' routines
- Policy impact
- Cost factors
- Obsolescence

- Alternative systems
- Regulatory restrictions on mobile radio

1. Current Purpose and Use of Mobile Radio

The current purpose and use of a system must be defined. When properly addressed, information will be visible concerning many of the day-to-day operations of the Borrower. If this definition is brief, the indication is that an in-depth study of the Borrower's organization relative to mobile radio applications may be in order.

As of the mid-1970's, the purpose of power industry mobile radio was to dispatch work crews to maintenance, repair or construction activities. Communications incidental to this are recognized as productive and encouraged as part of the field reporting use of mobile radio systems. Industry-wide, policy controlling radio network discipline has rested primarily in the hands of the dispatch function. Generally, this policy represents radio network use paced by the overall workload of individual dispatchers.

Members of the power industry are normally responsible for specific activities over large areas, or along an extended right-of-way. Because of their size, efficient control of daily operations is broken into geographical sectors, sections, or areas. Each such subdivision practices a degree of autonomous responsibility with central coordination. Likewise, the mobile radio dispatch is subdivided. Messages from one sector or section of the user's field force to another sector or section are usually relayed by the central dispatch operation. This relay function is in a manual mode as practiced today, and an operator's (dispatcher) assistance is required to perform patching operations if the mobile radio system has interarea communications capability. This represents a technology equal to the manual telephone switchboard, where the dispatch personnel must perform as the equivalent of the outmoded telephone operator.

If such interarea mobile-to-mobile communications cannot be interconnected, then the dispatch personnel are required to perform a voice relay function.

Another use of mobile radio which is also incidental to the dispatch purpose is in the form of field originated requests for materials, specific personnel, information, etc. The dispatch relay system is invoked as above or via telephone, and usually some manual record of message content is required.

Communications at a work location are an extension of the dispatch purpose. Mobile-to-mobile radio contact is widely used to coordinate the effort of a crew, or between crews dispatched to a common work area.

From the brief descriptions above, the dispatch concept represents the beginning of the considerations that should be undertaken in the preliminary phases of determining the current purpose and use of a mobile radio system. Broad questions such as the following require answers based upon the interrelation of the many business functions of the Borrower:

- Will the system provide only voice communications?
- Will data communications be useful?
- What tasks can be performed via a computer interface?
- Is dispatch service the ultimate requirement?
- Will automation expedite communications?

For the Borrower already committed to a mobile radio system, these considerations can be approached from the prospect of what additional purpose and use can be assigned to the system. For the Borrower just planning a new mobile radio system, these first considerations will establish the objectives for it in relation to all business activities, and aid in setting future requirements in perspective.

2. <u>Ten and Twenty Year Projected Use of Mobile Radio</u>

Mobile radio systems are not a static communications medium. System technology is expanding rapidly, taking advantage of the microprocessor and associated digital techniques. How far this trend will have progressed in 10 or 20 years is impossible to forecast. In spite of this, it is important that Borrowers consider at this time all possible areas within their business activities that can possibly benefit from mobile radio communications.

It is not too early to think in terms of all power industry services and operations that are amenable to computer technology. Each should be considered in conjunction with the question, "Will extension of this service or operation to the field be beneficial?" An obvious area where the answer is "yes" is that involving cost savings through efficiency. For example: work crews can be given immediate access to material inventory and availability; test routines can be made simple by the power of a large computer and can be run in the field; work orders can be received as page copy at the work site; safety procedures

can be monitored and verified; maps, diagrams and drawings can be transmitted to installation and repair locations; engineering departments can have immediate access to field survey data; personnel can coordinate variable arrival and departure times anywhere within the system.

The examples just mentioned will bring many more to mind. In projecting mobile radio use for 10 and 20 years years hence, the Borrower is on safe ground to include any organizational transaction that is not limited to the confines of one building or one facility. A list of these transactions will be long and varied, and should be reviewed in terms of business objectives and planning. Those thought applicable to the 10 year or 20 year projection should be identified accordingly. Long term projections for mobile radio application are of great use to the systems engineer, especially during system planning. From them due consideration can be made for mobile radio fixed location facilities. Traffic paths and their loading can be configured in a manner to accept expansion without rebuilding the system. Future radio facilities needs can be planned, and technical considerations complementary to the projected uses can be included in the system design. Overall, the mobile radio system can be made responsive to change without forced obsolescence of equipment and facilities; and the Borrower will have a baseline for determining the economic impact of the system and cost effectiveness over a reasonable life span.

3. Operation's Routine

Mobile radio system considerations should account fully for operation's routine, which is effectively the policy affecting day to day activities. Much of the operation's routine has evolved with the growth of the power industry and represents methods of handling transactions that predate the system technology of today's mobile radio. As an example, the interplay of accounting and engineering functions with the field personnel should be carefully considered.

Accounting functions are extremely important for cost control and early recognition of trends. Inventory management as a subject is cited. The simple task of knowing the disposition and availability of common hardware items is generally difficult, even though the computer has taken the place of the parts ledger. If planned for, the mobile radio system can be made into a field and facility extension of the computer like the automated cash register of other enterprises.

There is no reason that a material depot, no matter how remote, cannot be made a part of the mobile radio system such that field requirements can be processed and made ready for pickup or shipment on a real-time basis. Its record of each charge-

able transaction can be entered into computer control, and as the field force expends the drawn material assets, it completes a transaction with the computer. This example will be recognized by accounting analysts as a major step towards the ideal management of operating resources, i.e. accountability and control of inventory levels from acquisition to expenditure and through replacement. Original planning towards a fully automated inventory control as well as other accounting functions recommended by the organization's analysts should be included in the considerations which determine the mobile radio system's utility for the Borrower.

The application of mobile radio systems has generally ignored the engineering aspects of the power industry. Access to a scientific computer from field locations, or survey data recall from stored data, provides an on-the-spot tool that can avoid solving problems by using assumptions, estimates, and sometimes multiple trips. There is no technical reason to exclude the eventual transmission of sketches to a field site when a need arises to modify or correct some plan. To plan a mobile radio system that can be upgraded to provide these services represents foresight which will be recognized as cost-effective over the life span of the equipment.

Many other daily operation's routine functions will become apparent to the Borrower, such as disposition and availability of personnel, vehicles, major equipment, etc. How effectively the mobile radio system can integrate into the operation's routine is solely up to the Borrower's departmental involvement in considerations for the system's application.

4. Automation of Operation's Routines

Many operation's routines involve record making, forwarding, processing, entry, and storage. Many routines are partially computerized, although some hand transcription is necessary for most. Field activity is the area within the power industry where manual records are most prevalent. How much of the information generated by field personnel could be treated to full computer organization through the mobile radio system and vehicular data equipment is dependent upon the policies and requirements of the Borrower. These latter should be studied as valid working considerations of mobile radio planning.

Other operation's routines which are allied to the day-to-day operation of the mobile radio system are amenable to automation: consideration should be given to direct dial access to and from either commercial or private telephone facilities; selective calling to a specific mobile unit from dispatch or mobile radio station; interarea communications without dispatch assistance; automatic radio channel search for directed calls (for

a specific radio unit); a paging function to locate specific individuals; automatic record keeping for dispatch operations; call queuing and priority (emergency) derivation; automatic identification of call originator; automatic call routing; automatic situation response for calls directed to unattended work vehicles. These and other mobile radio operational functions require evaluation as part of the daily operations' routines that are governed by the Borrower's mobile radio policy.

5. Policy Impact

The impact of a modern or future mobile radio system upon organization policy is difficult to forecast. This subject is dependent upon the Borrower's current operational policy and the degree of emphasis placed upon the mobile radio system as a supporting tool. It can be conjectured that as Operations becomes more accustomed to the use of mobile radio for gathering data, a greater flow of information will be available for the functions of other departments. This may eventually require policy revision. Reports that may seem excessively time-consuming on a weekly or monthly basis may be updated daily with less effort. Statistical data which is now difficult to gather may become routine. In short, the Borrower will undoubtedly find an operational policy review beneficial as the mobile radio system is recognized as providing more assistance to the control and direction of the organization's functions.

6. Cost Factors

The decision to continue the manual control dispatch mobile radio system concept or to move into the automated multifunction system philosophy requires consideration of cost factors. A problem confronting the Borrower is the investment in a potential capability which may not be required for the next 5 to 10 years. Each case must be weighed in terms of initial and operating costs for the system's future application; the long term benefits require careful study.

There are instances in which the Borrower may not have the technological expertise to compile mobile radio costs for the variety of options available for meeting the system objectives. A degree of caution should be exercised in turning to manufacturers and suppliers for system quotations, as their primary business charter is equipment sales, and not necessarily a full understanding of what the power industry is trying to accomplish. Should the mobile radio system requirements be extensive, and the considerations for purpose, use, long range projections, etc. appear comprehensive, the services of an independent mobile radio systems consultant can be advantageous in the determination of cost factors.

Equipment cost is very often in direct proportion to its quality. If the equipment to be procured is expected to have a 15-year cost-effective life, then only the highest quality should be considered. Cost-effective life for communications equipment takes into consideration not only expected use before wear out, but also the costs of maintenance, down time, repair, and spare parts.

Another cost factor that can provide equipment savings on initial procurement is contained in the system design. In the past, high power was thought the solution to adequate mobile radio coverage. Since the advent of the hand-carried (personal portable) mobile station with its low power, the technology of propagation is more widely understood. Today the system trend is toward lower transmitting power and greater attention to base and mobile relay station location. The transportable mobile relay station is becoming most attractive, as it closes communications gaps usually associated with unscheduled or emergency activities. The need to provide blanket radio coverage of an area can be accommodated by a transportable facility that has an attractive cost factor in comparison to the fixed facilities that would be necessary for all contingency situations.

The greater the number of the Borrower's daily operating activities that the mobile radio system can participate in, the better the cost factor. Ideally, if enough communications traffic could be delegated to have the system fully active (loaded) 24 hours a day, an effective initial system cost several times that of the dispatch concept system cost would be reasonable. This introduces the cost per message as a real consideration. Most mobile radio users will find that this factor is not complimentary when evaluated for the dispatch concept system, but it is a good measure of the cost of system utilization. If the planning that this Bulletin discusses results in a projection of greater system utilization, then the message cost effectiveness can show a sharp improvement, and moderately higher system costs representing greater system flexibility will probably be acceptable.

7. <u>Obsolescence</u>

Two types of obsolescence exist for mobile radio systems:

- Equipment
- System application

The first is the classic case where equipment age is the major factor. This point of obsolescence is reached when the cost of yearly maintenance and repair is 4 to 6 times that of the first

5 year average cost after adjustment for inflation. On the surface, this maintenance and repair cost may not appear significant, but it does signal a loss of communications effectiveness and the expectation of possible catastrophic failure during an emergency. High quality equipment can be expected to provide 15 years of service life prior to obsolescence, assuming no damage from handling or other improper use.

System obsolescence is not as easily defined. A newly installed system can become obsolete within weeks of activation if it cannot perform its intended functions. In addition, a new system would be considered obsolete if it cannot accommodate automation without major modernization; if microprocessor control cannot be added in the future without custom interface development; or if the transmission characteristics are such that digital signaling would require new radio or terminal equipment. These examples represent a broad gauge of system obsolescence, which can be used in evaluating any mobile radio system that is considered for modernization. System architecture should be such that each of the above technological building blocks will fit comfortably without recourse to special design and development, or recourse to major alteration of the communications coverage and routing plan.

8. Alternative Systems

Considerations affecting the use of radio communications so far have concerned the transmission of bidirectional information. Cases exist within the power industry where one-way radio calls provide a vital service. Individuals engaged in activities calling them away from office oriented work locations such as marketing, customer service, administrative, or executive personnel can make excellent use of this communications form. Industry-wide, such a service is known as paging.

A paging system presupposes that an individual is engaged in activities that require movement within a geographical area, the provision that random requests for his services will be made, and that means of two-way communications are available for response to any request. Paging can be accomplished with tone signals only or with tone and voice signals, depending upon the type of radio receiver the individual carries in his pocket. The first mode requires that the recipient of an alert tone contact (by telephone or other means) a defined place or person to obtain the message. The other mode assumes that a voice message will be heard, understood, and acted upon, usually without direct acknowledgement.

Paging functions can be included in the power industry mobile radio system subject to FCC limitations. The principal technical requirement is the addition of a tone-code generator

and keypad at the dispatch position. This allows the dispatcher to key the calling number for a specific person and establishes a unique tone-code which is transmitted via the mobile radio base/relay stations. When received by the active paging receivers, only one unit will decode these code tones and sound the alert tone and (if applicable) receive a voice message. Those members of the power industry primarily engaged in metropolitan areas will find the paging capability a relatively inexpensive method for establishing communications with personnel. Contact can be established within buildings as well as when away from a vehicular radio at a work site.

9. Summary of Systems Considerations

Section B of this Bulletin has presented in narrative form a wide range of material that represents mobile radio system considerations. The intent is to generate consideration of additional subject matter that represents the Borrower's particular needs and applications. The subjects discussed are summarized below. The points requiring emphasis will have to be determined by the Borrower for his unique needs. System considerations are necessary for the managerial and planning decision process and should receive detailed attention during the early stages of system development. They represent the many factors that should be taken into account when formulating the implementation of a mobile radio system.

a. Documentation and Analysis of Requirements

The initial step in planning a mobile radio system is to establish the need and requirements. Requirements too often focus on the quantity of radio frequency channels and the number and location of base/relay stations. Requirements such as radio dispatch, radio-telephone, paging, personal portable radio operations, as well as possible future services, also require investigation, analysis, and careful documentation by both the proponent user organization and the mobile systems engineer.

b. System Concept Options

In the power industry mobile radio requirements employ a wide variety of techniques. The mobile system designer must consider:

1. The types of systems available

2. Their comparative advantages of flexibility, performance, reliability, ease of expansion, potential obsolescence, and maintainability

3. Alternate use or upgrade of existing facilities

4. Urgency of the requirements versus system availability

5. Regulatory matters concerning the use of the proposed system and user eligibility under FCC Rules

c. Cost Factors

As technology advances and equipment types diversify, the cost elements in a communications system become more flexible. Numerous technical/cost judgments need to be made in developing a system. Some of the major cost areas of the mobile radio system are:

1. Purchase cost - equipment, installation, training, spare parts, etc.

2. Cost of maintenance - logistics, test equipment, vehicles, depot repair facilities, personnel

3. Future expansion cost - more equipment, special interface requirements, more radio frequency channels, additional facilities and personnel, etc.

4. Equipment life - normal life cycle, unanticipated losses

5. Purchase versus lease costs

6. Funding - phased implementation, cost of money, inflation, depreciation

An important point is that a communications system is rarely static; its associated costs are never clearly reflected in the purchase price. No simple set procedure for cost analysis is universally valid. Each system must be carefully considered in its own environment for realistic cost factors. REA Bulletin 66-4 addresses the subject more fully.

d. Grade of Service

The quality of service has a significant impact on the design (and cost) of the system. Typical service characteristics that need addressing include:

1. Range of coverage

2. Circuit quality

3. Reliability

4. Availability

e. Borrower Resources

In addition to financial resources, the borrower investigating the implementation of a mobile radio system should consider:

1. Personnel for various technical and managerial functions

2. Capability "in house" for designing, procuring, installing and/or maintaining the system

3. Level of outside consulting required

4. Existing and needed plant, such as building space, vehicles, test equipment, etc.

5. Level of support and administrative activity available such as purchasing, accounting, personnel functions, etc.

Generally, when an organization becomes involved in a mobile radio system for the first time, there are many decisions to be made concerning its allocation of resources. There are many alternatives between the extremes of a 100 percent contractor turnkey project and a 100 percent internal implementation of the system.

C. Design Considerations

The final design of any communications system represents the integration of user requirements with technology to obtain adequate, current and projected service for a minimum expenditure of funds. Section A addresses the basic configurations of equipments and their capabilities. Section B discusses considerations in system planning. This section describes technical and other factors that require consideration. Once settled upon, these factors represent system design parameters that are met by the integration of requirements and technology. Attention to each factor must be thorough, as each will impact the cost to implement, operate, and maintain the system. Under- or over-design of a mobile radio system can have detrimental effects long after its commissioning. Major factors requiring consideration in the system design stage are:

- System service area
- Communications reliability

- Facility availability and acquisition
- Principal message format
- System operational reliability
- Communication support requirements
- Foreign system interface
- Call direction
- System control
- Field applications

Each of these is expanded in the subsequent paragraphs.

1. System Service Area

The service area for the mobile radio system is usually defined by the Borrower's geographical area of interest. This should be refined to determine sub-areas of no interest, areas of occasional interest, and areas of high interest for mobile communications. Such preliminary work represents the first step of a map study, and operational requirement determination. It causes consideration of the Borrower's service area by the various departments of the organization. Each of the areas of interest requires a topographic study such that elevations, urban areas, radio obstructions, forest land, etc. can be identified and outlined. Within each of these subdivisions of the service area, a degree of interest for mobile radio communications must be assigned. This can be done by using a scale of 10, or any other method to identify the degree of communications importance. From this part of the map study,primary and secondary radio service areas will emerge. This is the information vital to engineering design of the mobile radio system coverage.

Details contained in the service area map study will be combined with information growing out of the consideration of other factors to be discussed. When combined, the systems engineer will be able to pinpoint radio locations, facility needs, traffic flow, expansion limits and system operational requirements meeting the Borrower's need for mobile radio.

2. Communications Reliability

Communications reliability is closely allied to the breakdown of the system service area primary and secondary radio coverage areas. In the primary radio coverage area, the objective

should be 90% coverage. This means that adequate (intelligible) exchange of information between base and mobiles should be possible from at least 90 out of 100 random locations in the service area. In the secondary radio coverage areas, the objective can be lower - 75% or even 50% coverage. Usually a limit (i.e. in decibels, dB) is assigned as the worst case signal-to-noise ratio (SNR) that can be tolerated for communications meeting a certain level of intelligibility. To achieve usable radio communications meeting this criterion requires that the radio signal strength necessary to maintain the worst case SNR at the receiving location becomes the basic design factor.

Returning to the map study for a moment -- if isolated locations within a primary area are identified as poor radio reception areas, and also as containing little or no interest to the Borrower's operation, then they should not be used. A radio survey to determine variations of signal strength from preliminary transmitter locations can be very useful in setting the numerical design limits representing communications reliability.

Although the same degree of message understanding is required (i.e. the same SNR limit as used with the primary area), secondary areas can tolerate locations within their boundaries where total loss of radio contact is of no consequence.

3. Facility Availability and Acquisition

Most power industry Borrowers either own or control properties, buildings, and various types of structures within the mobile radio system service area. Economic considerations dictate that as many of these be made use of for the radio system as possible. In some cases using the Borrower's facilities may not result in a good design or be cost-effective. An example of this is an antenna tower. The decision to construct and maintain a tower on the Borrower's property, or to lease antenna and equipment space on another structure a mile or so away is usually made on a cost basis. Technically, the relatively small distance difference will not affect the desired radio coverage. The use of a TV station tower will usually provide greater mobile radio antenna height and therefore more radio coverage than possible from a modest tower erected by the Borrower.

Systems requiring relay stations are sensitive to facility availability. Many have been laid out in the past, making use of sites that were established for the power system's private microwave system. The users are readily made aware of mobile system deficiencies that can develop from this approach when two or more relay stations interfere with each other as is the

case all too often because the facility locations used were not engineered for mobile radio service. Should the Borrower be in the process of modernizing his mobile radio system, elimination of such troublesome communication locations should be a major consideration. Once identified, the systems engineer can offer viable alternatives to rectify the problem.

Equipment used at relatively remote locations such as relay stations, base stations, or control link stations is available today in outdoor mounting configurations. Fixed location equipment of this type no longer requires costly environmentally controlled shelter. If a location is desirable, but has no building on it, the radio equipment can be tower mounted. In instances where many pieces of fixed equipment are to be located at an unimproved site, the prefabricated fiberglass shelter becomes an attractive housing. For all intents and purpose, this shelter, antenna tower, power line construction, etc. can be classified as facility acquisition for the mobile radio system even though the real estate containing it is part of the Borrower's holdings.

In general, the system engineer should make maximum use of existing and improved facilities as a provision of mobile radio system design. But Borrower restriction to the use of only such facilities should not be permitted,as undesirable technical and operational compromises can develop out of hand. In order to assure design consideration of existing facilities, the area coverage maps (of the service area map study) should be annotated to show Borrower facilities and improvements that exist. Information of this nature allows the system engineer to make an initial system layout based upon facility availability, radio coverage, technology of propagation, support accessibility and other technical/economic factors. From this, recommended locations for facility acquisition, such as a relay station site, telephone circuit extension, leased tower space, etc. can be made.

Instances will arise where terrain and radio propagation considerations are such that use of existing facilities requires two or more fixed radio locations to secure coverage of a service area, but where the same grade and area of service can be obtained from a commanding location using one station. This situation should be carefully studied from an economic standpoint. Technically, the single station coverage is to be preferred, and the cost of equipment and maintenance will be minimum for the desired service.

Facilities that support the mobile radio system represent very basic economic considerations. Therefore the close coordination of engineering, real estate, construction, accounting, and planning departments of the Borrower are needed for the

decision process that determines the application of existing or acquired facilities for the mobile radio system. Likewise, this same coordination should exist for modernization programs where the abandoning of existing facilities seems desirable for technical or economic reasons.

4. Principal Message Format

A system consideration that is often overlooked in the design of mobile radio networks is the principal message format to be used. In reality there are two types of messages: the signaling message that establishes the system control protocol (i.e. machine intelligence) and the voice message used to direct the organizations' operations. Both types possess a principal format needing attention during design considerations.

The signaling message format is almost wholly technical in nature as it represents the conversion of a human request for some machine function to take place. Historically mobile radio signaling was limited to turning a remote transmitter on and off, or ringing an operator for service. Recently data transmission coding and decoding schemes have been introduced which permit the calling of individual mobile stations (i.e. selective calling or paging).

These were accomplished via a message format consisting of discrete tones in some prearranged sequence. In the early 1970's the format for these same signaling functions began a transition to that used by the telephone industry. This is known as dual tone multiple frequency (DTMF) signaling, or by the Bell Telephone System's name of Touch Tone[R]. The advantage of the DTMF format is higher reliability and the adaptation of proven signaling functions, equipment and transmission compatibility.

From the standpoint of mobile radio equipment complexity, this format is essentially an even trade with that of the sequential, discrete tones. As DTMF became better understood by mobile radio system designers, the format was found sufficiently reliable to execute more complex control functions such as automatic network switching, calling unit identification, precoded status signals, call acknowledgment, etc. The major limiting factor for DTMF has been the length of time necessary to transmit a comprehensive signaling message using this format. Therefore the system signaling protocol did not develop rapidly.

In the mid 1970's advantage was taken of the development of the microprocessor to perform high speed equipment and system control under preprogrammed conditions. By placing all of the

R registered trademark

possible operating sequences of a mobile station into the inexpensive memory bank of the microprocessor, only a short signaling message was needed to identify and call up the operations representing the system protocol desired. The first format for this application was DTMF. Once design engineers began to use the microprocessor, it was found that its potential for interactive system control would not be realized with the signaling time required by DTMF. Thus, about 1976, a move towards a frequency shift (FS) format for the signaling message was made practical by the introduction of suitable mobile radio system components. Because of the greater speed of FS compared to DTMF format and the power and flexibility of the microprocessor, the individual radio stations comprising the mobile system can engage in a machine-to-machine signaling dialogue, and routine interactive functions are completed faster and with greater accuracy than possible using manual or sequential tone operations.

The FS format equipment is currently more expensive than DTMF. This is to be expected for a development that has as yet to reach a production level where competitive marketing takes place. Even with this disadvantage, the FS signaling message format in conjunction with the microprocessor should be considered for new systems or networks. The Borrower will find the flexibility of this message format/processor to be cost-effective over the life of a new system as it is receptive to inexpensive protocol changes (i.e. changes in preprogrammed instructions - software) consistent with the Borrower's operations.

The second message format requiring consideration for system design purposes is the spoken word. The organization using routine messages that can be easily recognized for content or contain fixed and often repeated instructions can establish a communications format that lends itself to message recognition under very poor radio conditions. An example of this type of format is the familiar "10-code" used by police and other public safety organizations. The other extreme of message format is represented by the communications required for radio dispatched taxicabs. This represents the most difficult to achieve success with as each message is unique, and total understandability is essential.

The power industry mobile radio message format is a hybrid. Many of the dispatch type messages can make use of easily recognized and standardized phrases. Other communications consist of a series of unique instructions such as switching orders, where there is no operational room for error. Such communications require maximum voice intelligibility and total verification for correctness; therefore, the mobile radio communications circuits must be of the highest quality. Information of this nature is used by the systems engineer to develop

minimum transmission criteria which must be recognized as having an impact on system cost.

Recent developments in the field of FS signaling as discussed above indicate that organizations having the hybrid voice format requirement may be able to combine voice and FS for its messages. Routine dispatch message types can be voice; unique instruction messages can be via FS format. The latter provides very dependable communications under conditions that would make voice most difficult or impossible.

The method to obtain the degree of message service via the mobile radio system is a coordination commitment between the Borrower and the systems engineer. A message study is required to identify the types of messages that are most sensitive, for the proper operation of the organization. From this the transmission criteria and format are determined, and a level of system reliability and cost is established as the detailed engineering progresses.

5. System Operational Reliability

System operational reliability is a statistical prediction based upon electronic component failure rates and their effects upon equipment making up the system. Each identifiable equipment can be assigned a mean time between failure (MTBF) in hours, using prediction techniques and figures such as found in MIL-HDBK-217A. These can then be used to form the statistical base on which to predict the mean time between system failure (MTBSF) which will represent the mobile radio system design goal.

The system operational reliability is normally much greater than any of its parts, as can be readily illustrated by the failure of a single mobile radio which has no effect on continuing system operation. On the other hand, the failure of a base station can definitely restrict the mobile system operation. From this, the conclusion is that the base station must have a predicted reliability that is greater than the mobile station. Two ways are available to effect greater reliability. The systems engineer normally makes the design choice. One method utilizes redundant equipment for those system functions that are critical for operational reliability. The second method is to increase the quality of critical equipment until the MTBSF objective is assured. The choice is usually a cost/need type of design consideration, and to a degree the development of schemes to work around certain types of system failures.

6. Communications Support Requirements

Mobile radio system design for either a new system or the modernization of an existing one requires consideration of

support functions. Typical of those that can impact technical complexity and cost are:

- Factory or user repair
- Contracted maintenance
- Spare parts logistics
- Spare equipment logistics
- Technical skill of user's personnel
- Technical training for new equipment
- Operational training
- Facility maintenance
- Vehicle installation
- Dedicated maintenance vehicles and personnel

Most power industry mobile radio systems are privately owned and operated; therefore, any form of contract maintenance may have no bearing on the considerations. An exception to this may exist for the Borrower implementing a new system with limited coverage. The factors determining the point where user maintenance is more economical than contract maintenance require considerations for the individual cases.

Of concern is the possibility that a system design can evolve which will cause the cost of support requirements to increase out of proportion. Therefore support cost projections sometimes act as a signal that an overly ambitious system design exists. Mobile radio communications like all other communications modes require engineered compromises between operations, technology, and costs.

7. Foreign System Interface

As the mobile radio system expands, interfaces with other communications systems become more desirable. The telephone system is the most applicable to normal operations of the power industry. Borrowers operating a private telephone system may wish to maximize their mobile communication capability by extending its flexibility to the vehicle. A common carrier telephone interface is also desirable, but requires some form of call control in order to regulate the cost of its service.

Historically the mobile-to-telephone interface has been controlled by the power industry dispatcher. Such control is

still desirable for calls directed outward via the common carrier. On the other hand, efficient interplay of the Borrower's private telephone and mobile radio system cannot be reached when each call requires dispatcher attention. Today's technology and competitive manufacturers provide a range of telephone/radio system interfaces and control equipments permitting automatic interface operations. When equipped with dialing capability, the vehicle radio can access and dial calls to any telephone of a private automatic branch exchange (PABX) through automatic interface equipment.

Another type of foreign system requiring an interface exists when the Borrower's mobile radio system is comprised of autonomous networks, each reporting to its own dispatcher. When coordinating action of the dispatcher is required to complete a mobile radio call from one network to a mobile or facility of another network, this manual interface becomes limiting to communications. The requirement for the network-to-network interface needs to be examined, and if found to be a desirable operational tool, automation should be considered. Such automation can be designed to utilize the same dialing capability (at the mobile station) as applicable to the PABX discussed above.

Technically mobile radio system interface requirements will be similar to those of the telephone industry. Several manufacturers have "phone patch" type of equipment on the market, and it is anticipated that any form of signaling format compatible to the radio system will be available from many sources in the late 1970's.

8. Call Direction

Call direction for a mobile radio system is the protocol that determines how Station A talks to Station B. For the small system, as earlier depicted by Figure II-6, the base station under dispatch (operator) control acts as the call director. Mobile stations address their calls to the dispatcher. Messages are passed through him, and requests for mobile to mobile communications are routinely cleared. (The latter is a network discipline necessary to prevent indiscriminate use of a single channel network.)

As the size and complexity of the mobile radio system increase, so do the call direction options. Therefore it is necessary to establish the operational procedure for calls made to and from mobile units as a function of preliminary system design. Radio systems dedicated to metropolitan area communications require different call direction than the systems providing coverage along an extended right-of-way. In general, the Borrower's departments need to establish basic definitions and rules governing calls in the categories below:

- Emergency
- Priority
- Mobile to dispatch
- Mobile to mobile intranetwork
- Mobile to mobile internetwork
- Mobile to land-telephone
- Dispatch to mobile
- Land telephone to mobile

From the preliminary consideration of the call categories, a call hierarchy will develop and the architecture of call direction will be visible for the system engineer's application to the overall design considerations. As an example, the engineer can provide in the system design the ability for one mobile to direct a call to another mobile either directly or through a relay station. Or the design will permit direction of the same mobile to mobile type of call via two or more relay stations as may be necessary for the extended right of way mobile radio system. The call direction architecture will indicate whether or not relay stations require a choice of operating frequencies, or should be made combination base and relay stations.

For the Borrower, the study of call categories by internal groups using mobile radio communications will materially aid future planning for effective use of the system capabilities.

9. <u>System Control</u>

Early in the mobile radio system design, decisions must be made concerning the type of system control to be used. Essentially, this is a process of determining what control operations are to be automated in order to provide adequate technical capability for the affected equipment. Large mobile radio systems with a fleet of 200 or more radio-equipped vehicles can justify a greater degree of automation than smaller systems. Generally, a system supporting a fleet of 500 or more units should be designed to accommodate the maximum control automation possible. If the Borrower is in the process of modernizing a large system, it is best to plan the automation of the control operations in stages such that existing equipments will not be driven into premature obsolescence.

Simple mobile systems utilizing one communications channel for extended dispatch and mobile coverage (i.e. base station/relay station operation) and a second channel for local coverage (i.e. mobile to mobile) can be designed using the least automation for control. The relay station is the only system radio that is required to perform definite functions upon recognition of a specific signal without positive manual override. In its elementary form, this control operation detects the presence of a mobile radio carrier with a control tone. If the combination of carrier and its tone are valid, the relay station control logic will turn on its transmitter, establishing the radio relay circuit for the mobile station. Common design practice is to maintain the relay station transmitter on for a few seconds after the end of the mobile transmission. This allows either the dispatcher or another mobile station time to initiate a reply (i.e. key their push to talk (PTT) circuit) without recycling of the relay station turn-on functions for each transmission of a two way communication. The automation of the relay station on-off function is completed by a safety device (time-out-timer) that will cause positive transmitter shut down in the event the transmitter's on time exceeds a preset duration. The remaining system control operations are normally manual, and most come under system operational procedures to be adhered to by all personnel. Simple administrative directives such as "listen before making a call to avoid interfering with other communications", and "return channel selector to channel 1 (extended coverage) after completing use of channel 2 (local coverage)" must be enforced for proper network operations.

As the system size grows, the desirability of providing more complex control operations in an automated manner is more apparent. Examples of such operations are listed below.

- Call direction to a specific mobile unit (selective calling)
- Call direction via a specific relay station
- Emergency/priority call recognition
- Dispatch and mobile station all-call
- Direct telephone (private system) access for mobile
- Direct mobile access from telephone (private system)
- Calling station identification
- Called station return identification
- Call routing in multi-network system
- Executive override

Operations such as the identifier (number) of a specific mobile station are manually entered by the dispatcher, but all search and find control steps used by the mobile radio system can be automatic.

Ultimate system control is designed to be a human decision function. The right to override automated control operations is normally delegated to the dispatcher. Because of this control responsibility the dispatcher is normally provided with visual and aural monitoring functions that keep him informed relative to system activity and operation. Systems that consist of autonomous networks normally have the network dispatch desks (consoles) linked so that any can assume system control in an emergency or for operations that are handed off from dispatcher to dispatcher.

The efficiency of the mobile radio system control operations and the communications capability (i.e. number of messages per hour, etc.) are directly related. A large mobile fleet that is served by an automated system will be provided with more beneficial communications hours per month than possible with manual control techniques. Serious consideration of all factors representing the degree of system control required by the Borrower is required. Determinations should be based upon operational need and system growth projections, leaving the cost factor as the item of least priority. Experience has shown that major redesign of large systems to increase their communications control efficiency is beneficial and cost-effective for the user.

10. Field Applications

How the mobile radio system is to be used in the field will have a bearing upon its design. As described previously, the primary application of mobile radio in the power industry is as a dispatch tool, sending work crews to specific locations, and the coordination of reports from these operations. Another application, which is independent of the dispatcher, is the use of radio communications between field crew members at a work site. This type of field service lends itself to the hand-carried (personal portable) mobile station. Emergency and natural disaster situations call for communications planning around the vehicular and hand-carried mobile radios. Access to the normal radio network for such a contingency must be established as part of the system design.

Other field applications exist in the area of logistics and engineering data. For the first, construction and maintenance foremen require direct access to supply yards and equipment shops. For the second, engineering and survey crews in the field have in the past experienced isolation from data which if available would eliminate additional trips to obtain the data.

These general field applications represent long duration communications because of their information content. They also can represent a need for communications from a location or area not adequately covered by the Borrower's primary mobile radio system. In order to accommodate these field uses of the system, design consideration is required concerning the establishment of special temporary circuits that can:

- Extend the radio range of the primary system
- Access logistic facilities and engineering offices without tying up the primary system

Each Borrower will have a unique set of field application circumstances that require study before the systems engineer can offer a design scheme that will complement the organization's operational need for mobile radio communications. Trade-off conclusions must be derived, and the projected long term effect on system costs must be known.

D. Design Objectives

Sections A, B, and C represent a comprehensive introduction to the many complex subjects that confront the Borrower and systems engineer when setting out to design a mobile radio system. This section will present the concept of design objectives affecting three system parameters:

- Service area
- Grade of service
- Traffic capacity

By definition, a design objective is a system operational parameter (identified by either a precondition or a study) that represents a desired capability which is addressed in the engineering design. Design objectives can be either over or under achieved. The latter often occurs in the course of system implementation due to the introduction of previously unknown factors. An example of this condition follows. Assume that during the design phase the radio frequency signal-to-noise ratio objective for all major receiving locations was specified as 18 dB. Preliminary data concerning all such identified locations indicates that this objective could be met in the worst case by a mobile signal of 10 uv/m. System design was then predicated upon this figure (and subsequently satisfactory signal strength measurements were made), but during system implementation a manufacturing plant near the main base station started a product process that utilized extensive arc welding techniques. The radio noise increase at the receiving location affected now made the signal-to-noise ratio 12 dB, clearly not meeting the design objective.

Many cases arise which can cause degradation of design objectives. Each of these can be accorded remedial treatment when identified, but additional cost is usually involved because of increased system complexity. Therefore close coordination between the Borrower and the systems engineer is needed, and the Borrower must be fully appreciative of recommendations that are made in an effort to preserve the design objectives within a reasonable cost structure.

1. Service Area

Each Borrower has a geographic area associated with his operations. It can be assumed that this area represents the gross primary service area for mobile radio communications. This area is then treated to a map study as described in detail under Section C, subpart 1. As mentioned therein, terrain and urban features representing impediments to mobile radio communications require identification as well as the specific area locations representing the Borrower's mobile communications needs.

As a second part of the service area map study, it is necessary that the Borrower identify future business or expansion plans that will take place outside of the gross primary mobile radio service area. The geographic areas so identified can then be considered in terms of secondary or fringe service areas (in reference to the primary service area). As a design objective affecting all service areas, a minimum radio frequency signal strength parameter will be assigned. This parameter contains many complex considerations affected by speech intelligibility requirements, receiving equipment specifications, antenna designs, etc. Once established, this design objective sets the essential quality of voice communications for primary, secondary, and the fringe service areas. The obvious question that now arises is, "What is the criterion that differentiates one service area from another?" The answer is, "The percentage of all of the possible receiving locations in a specified area that will meet the signal strength design objective a certain percentage of the time." From this answer, the service area can be defined as: "Contiguous blocks of land area, each representing a mobile radio communications location, which if considered as a whole would exhibit a certain probability of meeting the design objective." Because of the factors affecting radio propagation, it is more than likely that secondary and fringe service areas will appear within the gross primary area marked out in the map study. Several of these factors are discussed below. If they exist in a manner that requires special system design treatment in order to maintain the primary service area design objective for certain locations within the gross primary area, system complexity and cost can be expected to increase.

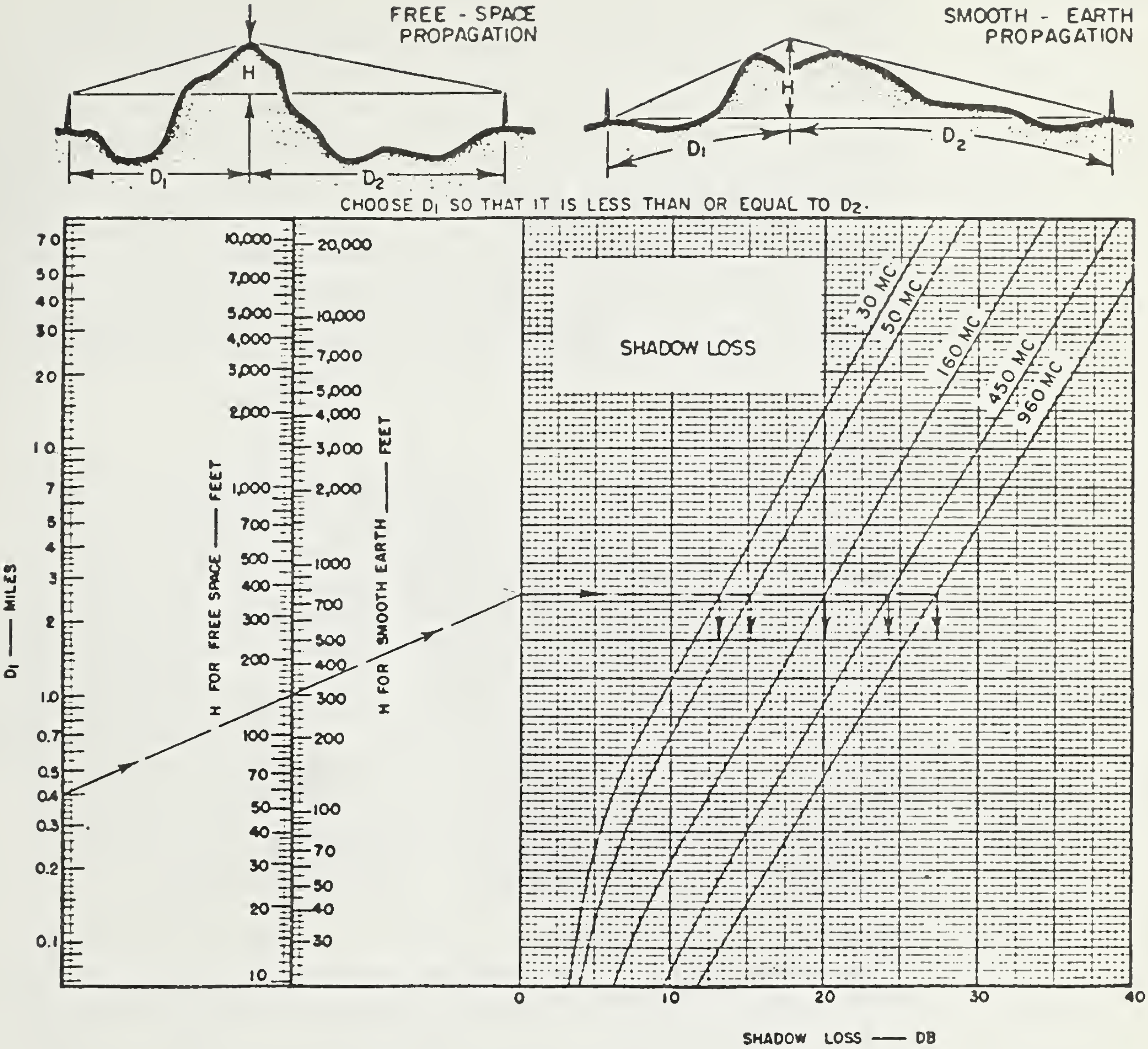
The ideal primary service area can be thought of as existing on smooth earth, with a single base station at its center, providing any mobile radio located at random in its boundary with 100% intelligible communications at all times. Theoretically, if the base station antenna can be located high enough, the line-of-sight radio propagation assumed for VHF and UHF mobile radio use would cover an infinite area, and transmitter power requirements would be modest as only that expended for free space loss plus the design objective signal strength would be needed.

The practical gross primary service area contains many modifying factors. Terrain, manmade structures, vegetation and electrically noisy areas represent the major categories, all of which can cause loss of radio signal strength. Terrain and structures can also cause radio signal degradation by reflection or refraction, resulting in the multipath phenomenon (the reception of two or more signals from a given radio station, caused by a combination of direct path and/or indirect path(s) such that there is a phase difference at the receiving location).

The concept of radio shadow formation(Figure II-16a) is easily demonstrated in the field. The depth of a given radio shadow can be measured, but for system design, empirically derived "shadow loss" data is found adequate for engineering to service area design objectives. This type of loss caused by terrain can become very troublesome when sharp ridges exist within a gross primary service area or if high cliffs separate parts of the area. Urban areas can suffer from radio shadows caused by large blocks of tall buildings. A large building when taken alone has a lesser shadow effect, except when the mobile is located within a few feet of its shadow side.

The multipath phenomenon, where signal distortion is prevalent, is usually caused by the reflection of radio waves. Urban areas are very susceptible to this problem as many manmade structures exist which form good reflecting surfaces that bounce radio waves back and forth in a manner that makes a given signal appear to come from a multiplicity of sources, all out of phase with each other. This problem becomes worse as structures' size and cover over an area increases.

Another common cause of signal loss is the effect of vegetation. All plant life absorbs radio energy at rates that vary for different frequencies. Tree cover is of major interest for mobile radio service areas, although some seasonal change can be projected for locations within tall crop (e.g. corn) boundaries. The effect of tree cover is a factor for suburban service areas, as well as right-of-way service areas bounded by forest. The very real possibility exists that primary service area design objectives may be too costly to achieve in heavily wooded areas



This graph is used to determine the shadow loss, due to an obstruction in what is otherwise a line-of-sight path. Where both antennas have 0-.6 Fresnel zone clearance, the "H FOR FREE SPACE" scale is used. Otherwise, the "H FOR SMOOTH EARTH" scale is used. D_1 is the distance from the obstruction to the nearer antenna.

To determine the shadow loss, draw a straight line from the D_1 scale through the appropriate H scale to intersect the zero shadow loss line. From the zero line, proceed horizontally to the curve for the appropriate frequency and read the loss below.

Figure II-16a Shadow Loss

and a lesser probability figure will need to be assigned. Experience within such areas, once the system is operational, will demonstrate particularly troublesome locations which can be avoided when making mobile radio calls. The subject of attenuation due to trees has been approached off and on since the early days of WW II. To date, the material is not very exhaustive, yet mobile radio transmission papers and texts recognize the problem. In order to illustrate the real concern that this subject represents, Figure II-16b shows what attenuation can be typically expected from moderately dense tree cover over the frequency range of approximately 40 to 500 MHz. The conditions represent a mobile station operating from a highway running through a grove of trees which separates it from a base station 12 to 25 miles distant.

2. <u>Grade of Service</u>

Grade of service and service area for a mobile radio system are so dependent upon each other that it is difficult to separate them. For standardization purposes, a communications circuit merit grading is used, as shown in Figure II-17. Mobile radio systems such as used by the power industry normally set the design objective for primary service areas at circuit merit grade CM3 for voice communications. For those Borrowers that use the mobile radio system to transmit switching and other orders requiring 100% copy of numbers or sequential operational instructions, circuit merit grade CM4 should be used. Figure II-18 is a graph of the signal power required for the CM3 grade of service. This same graph can be utilized for CM4 by adding 10 dB to the required signal power levels (i.e. a -120 dBw level for CM3 would be -110 dBw for CM4).

Choosing the design objective grade of service is the first step, applying it to the service area becomes a succession of small steps that will eventually complete the mobile radio system coverage study. As is indicated by Figure II-18 the received signal power required for designated locations and other Borrower interest areas within the gross primary service area becomes a design objective system parameter which defines the grade of service. Such a number is used in conjunction with signal power loss factors such as:

- Distance (free space)
- Terrain (shadow, diffraction)
- Ground cover (absorption)
- Transmission lines

and signal power gain factors such as:

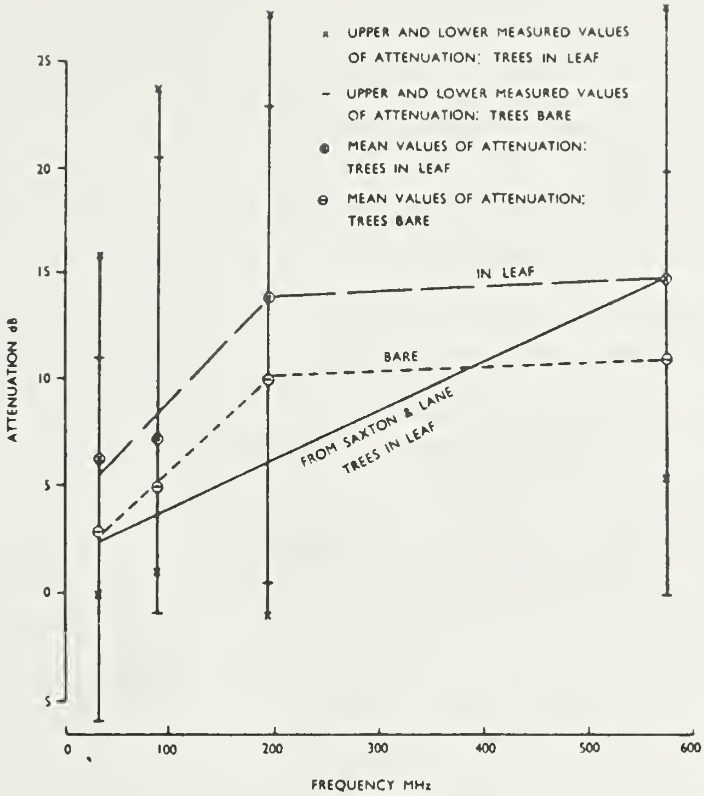


Figure II-16b Typical Mean Values of Signal Attenuation To Be Expected From a Grove of Trees In Close Proximity to a Mobile Radio Station

		Speech-to-Noise Ratio dB	
Circuit Merit	Definition	Nominal Value	Range
CM5	Perfectly readable, negligible noise	---	above 30
CM4	Perfectly readable but with noticeable noise	22	16 to 30
CM3	Readable with only occasional repetition (commercial)	12	9 to 16
CM2	Readable with difficulty, requires frequent repetition (noncommercial)	7	5 to 9
CM1	Unusable, presence of speech barely discernible	---	below 5

Figure II-17 Circuit Merit Grades

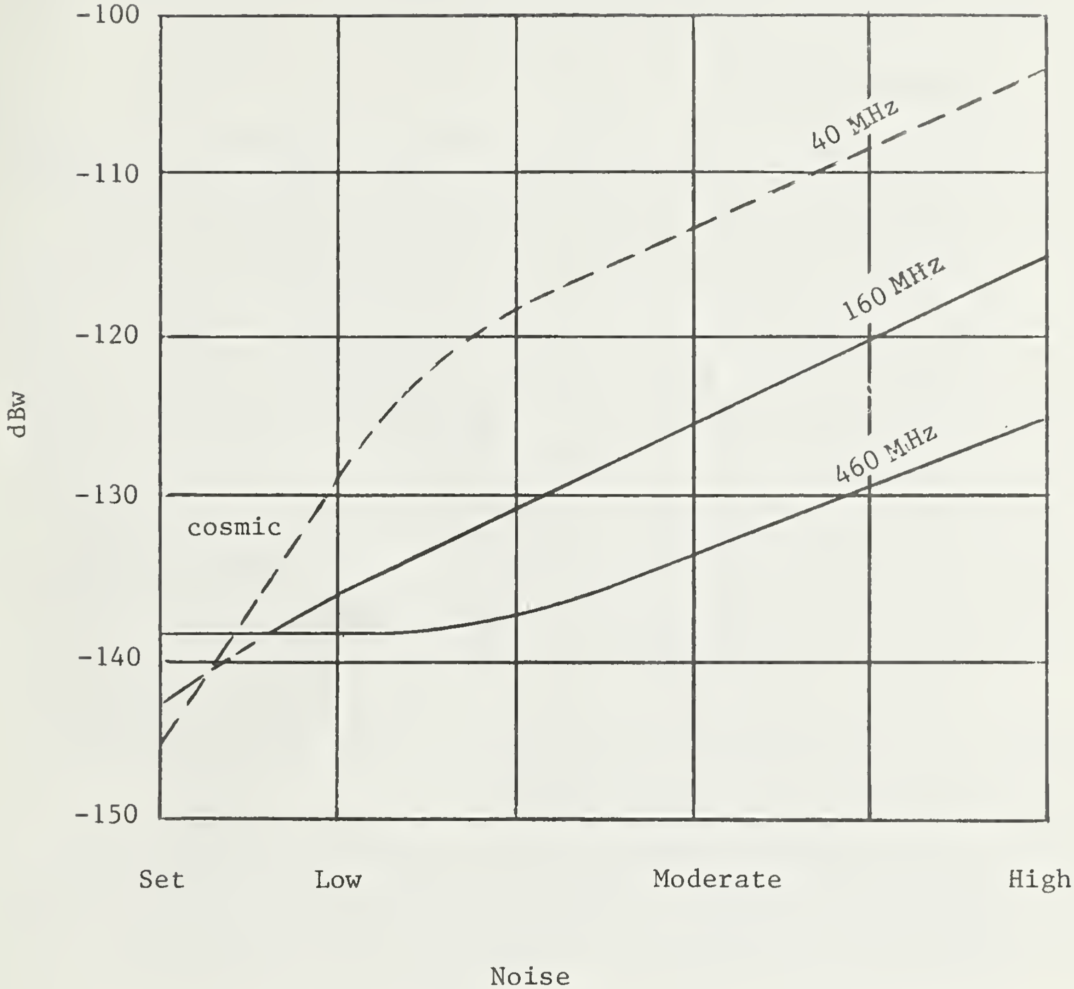


Figure II-18 Required Signal Power For CM3

- Antenna (over an isotropic)
- Transmitter power (objective to be the least necessary for grade of service)

to arrive at base and relay station locations. The complexity of each factor is such that in-depth study beyond the scope of this Bulletin is needed to demonstrate their interplay in designing to the service grade objective.

3. Traffic Capacity

The term "traffic" is used to designate the movement of messages over communications circuits. A simple mobile radio system utilizing one radio frequency channel exhibits one circuit. A complex system as encountered in power industry right-of-way applications may consist of single channel radio networks operating independently. These networks can also be arranged to simultaneously carry more than one message. Traffic capacity is a statistical design objective, being based upon long term conditions. The basic intent of such an objective is to render a system design that will offer to its users an overall minimum delay in the transmission of their calls or messages.

Practically all of the events and criteria used in traffic studies by the telephone industry are applicable to mobile radio systems. One traffic statistic which differs because of the power industry related message subject matter is the length of a call (message) in call units (CU) (minutes or seconds as applicable). At this time, sufficient power industry call data is unavailable to establish the base; therefore, an assumption of 2.8 CU per message (minutes) will be used for illustrative purposes.

Using the above assumption as an operating parameter, the simple single radio channel mobile system would be capable of handling 21 messages per hour; over an 8 hour working day, 168 messages. These would be divided between dispatch/mobile and mobile/mobile calls.

If the simple system consisted of 100 mobile radios, each could transmit 1.68 messages per day. For an active organization with 20 field crews, there is reason to believe that 8.4 messages per day per crew may be adequate, except for cases where radio is used to continuously coordinate work effort requiring interaction of personnel.

The simple system example has presupposed that the need for communications is at a constant level throughout the work day. This is a fallacy, as experience shows that the power industry mobile radio system exhibits traffic busy hours (the same as

the commercial telephone system does). These periods usually occur at the beginning and end of the work day. This is readily apparent in a dispatch system where work orders are relayed to crews as they leave their staging points. For a 20 crew dispatch, 56 or more minutes of message time would be needed (using the assumed statistics). A similar situation exists at the end of the work day when each crew reports to the dispatcher. During the busy hours, other radio calls are assumed to take place (100 mobile radios in service). These can encounter a system busy condition resulting in an unplaced call. Therefore, within the busy hours the time to complete a call can be materially increased. How much delay in call completion can be tolerated within a system requires study of the Borrower's operations. As the lost call or call completion delay criteria approaches zero, the cost of providing such service increases out of proportion. A workable compromise is usually determined by the traffic engineer in terms of lost calls per busy hour and/or busy hour time to complete a call. For a simple single channel mobile radio system, the additional equipment cost to achieve double the traffic capacity during the busy hours would be primarily that needed to activate a second radio channel. Base and relay stations cost would double; the same would apply for dispatch control positions. Mobile radio cost would increase by approximately 10%. During busy hour operations dispatch personnel handling radio traffic would also double. This additional system traffic capacity is cost-effective for the Borrower experiencing busy-hour conditions similar to those of the illustrative example, or when the mobile radio fleet reaches 100 or more units.

When the number of mobile radios in use exceeds 200 or 300 units, and radio coordinated work effort (interaction of personnel of a crew or between crews) is common practice, the traffic capacity is usually found excessive for a 2 channel mobile radio system. At this level of work-related activity, the system engineer will usually recommend a third radio channel dedicated to serve mobile to mobile communications only. The cost of such a channel is relatively low, as it affects only the mobile units.

In summarizing the traffic capacity design objective, the methods used by the telephone industry are valid for the mobile radio system.

Because of the statistical nature of communications traffic, the following information is required from the Borrower or must be assumed during the system design phase:

- Dispatch/mobile calls per normal 8 hour work day
- Mobile/mobile calls per normal 8 hour work day

- Busy hour dispatch/mobile calls
- Busy hour mobile/mobile calls
- Lost calls: busy hour dispatch/mobile
- Lost calls: busy hour mobile/mobile
- Total lost calls: dispatch/mobile per 8 hour work day
- Total lost calls: mobile/mobile per 8 hour work day
- Average call holding time (to include all time involved from first through last transmission for each specific call sequence)
- Number of dispatched work crews
- Average holding time of dispatch work order call
- Number of mobile radio units in use
- 10 year projection of number of mobile radio units
- 20 year projection of number of mobile radio units
- Maximum number of lost calls per 1000 that can be tolerated by operations.

From the above data the number of radio channels required to maintain the call service indicated by the lost calls per 1000 criteria can be projected for present and future operations. And each item listed becomes a real system design objective representing traffic capacity. The study of traffic engineering is complex, requiring extended experience with the subtle variations of communications statistics. As such, it is considered beyond the scope of this Bulletin.

E. Mobile Radio Equipment

1. Introduction

The purpose of this section is to provide an overview of the principal equipment utilized in Power Radio Service mobile radio systems. An exhaustive description of all available mobile radio equipment would be both voluminous and beyond the intent of this Bulletin. If the reader requires additional information on specific equipment, he is advised to contact manufacturers and solicit specification sheets, or to refer to the bibliography.

Figure II-19 shows the principal equipment elements that comprise typical mobile radio systems. All land mobile radio systems, from the simplest to the most complicated, share three common elements. These are:

- Land Station(s)
- Mobile Station(s)
- Control Point(s)

2. Land Stations

A land station is a fixed radio station not intended to be used while in motion.[1]

A land station consists of a transmitter which may range in RF power output generally from 10 to 330 watts, a receiver, a power supply and a control shelf. Land stations may be equipped to operate on one, two, four or more channels, but most stations are equipped with a single channel. The channel(s) may be single frequency (simplex) or two frequency (duplex). Land stations are connected to antennas by coaxial transmission lines. Antenna systems and transmission lines are discussed in Section E.6.

1. As defined in FCC Rules, Part 91, Paragraph 91.3

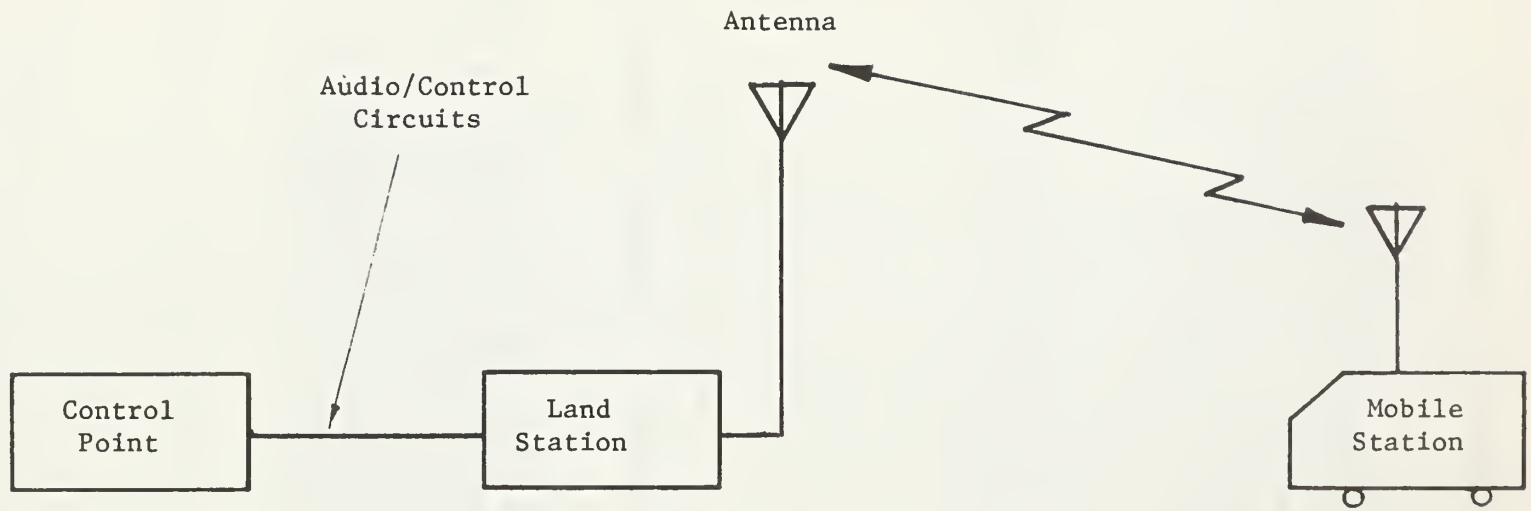


Figure II-19 Principal Equipment Elements in a Mobile Radio System

There are three general categories of land stations in the mobile service:

- Base Station
- Control Station
- Mobile Relay Station (Repeater)

Each of these categories is discussed below.

a. Base Station

A base station is a fixed radio station whose operation is directly controlled by a control unit at a designated control point. The base station may be locally controlled or remotely controlled over a physical (wireline) or radio link. Control Units are discussed later in this section under the heading of Control Points.

Figure II-20 shows the configuration of the two principal types of base stations.

Base stations can be supplied with physically separate transmitter and receiver or both in the same cabinet. The former are sometimes used in large systems where it may be convenient to have separate transmitter and receiver sites.

b. Control Stations

A control station is an Operational Fixed Station [fixed land station], the transmissions of which are used to control automatically the emissions or operation of another radio station at a specified location.[2]

Control stations are normally used to control a base station or a Mobile Relay Station (Repeater). Figure II-21 shows two control station configurations, one to control a base station, the other to control a mobile relay station (repeater). There are many configuration schemes possible, depending on the mode of operation of the base station (e.g. single frequency simplex, two frequency half duplex, or full duplex).

Control stations may be authorized to operate on frequencies authorized for point-to-point use. In addition, a control station associated with one or more mobile relay stations may, at the option of the applicant, be assigned the frequency of the associated mobile station.[3]

---

2. Op.cit.
3. Op.cit., Paragraph 91.7

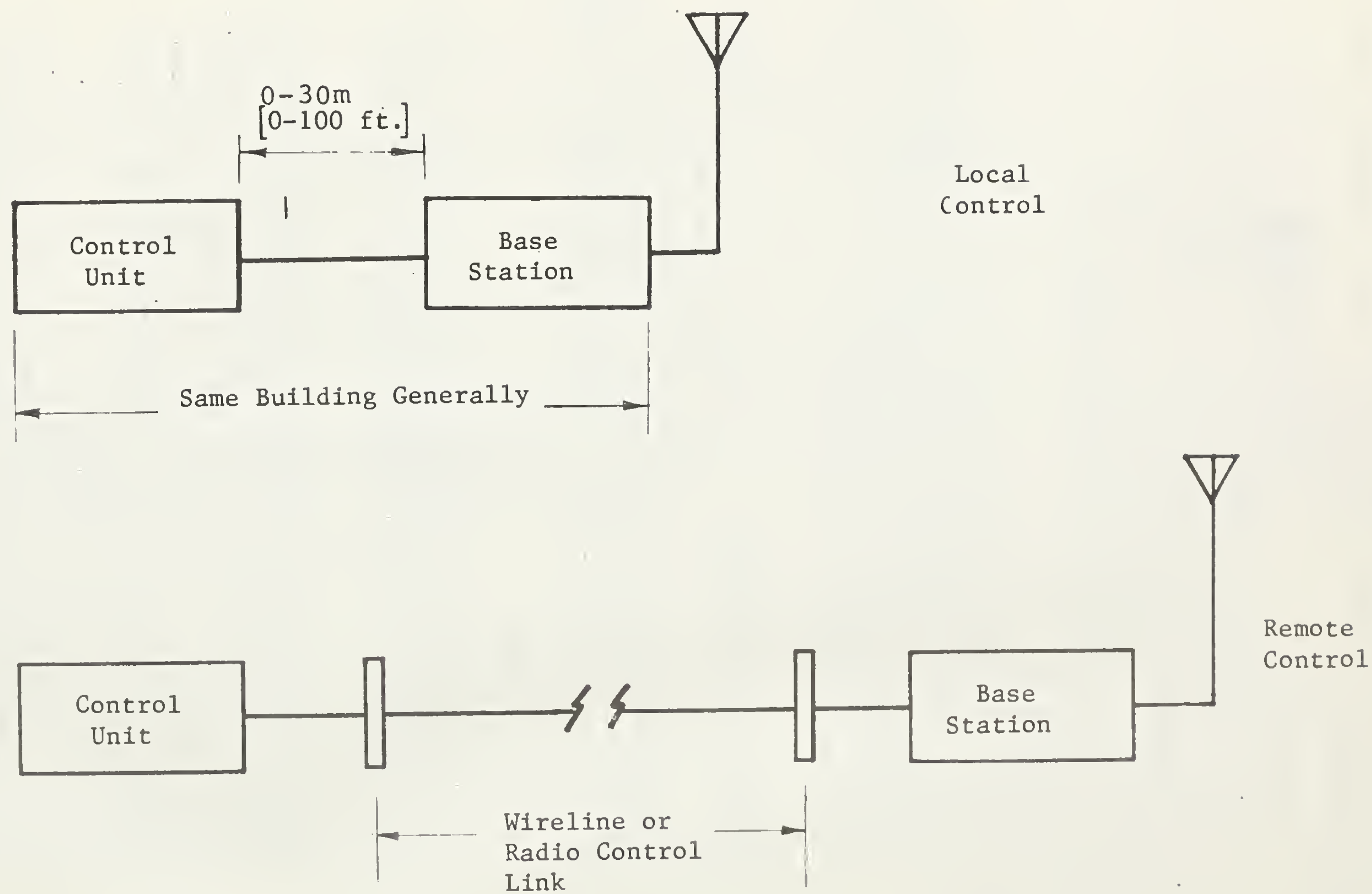


Figure II-20 Two Principal Types of Base Stations

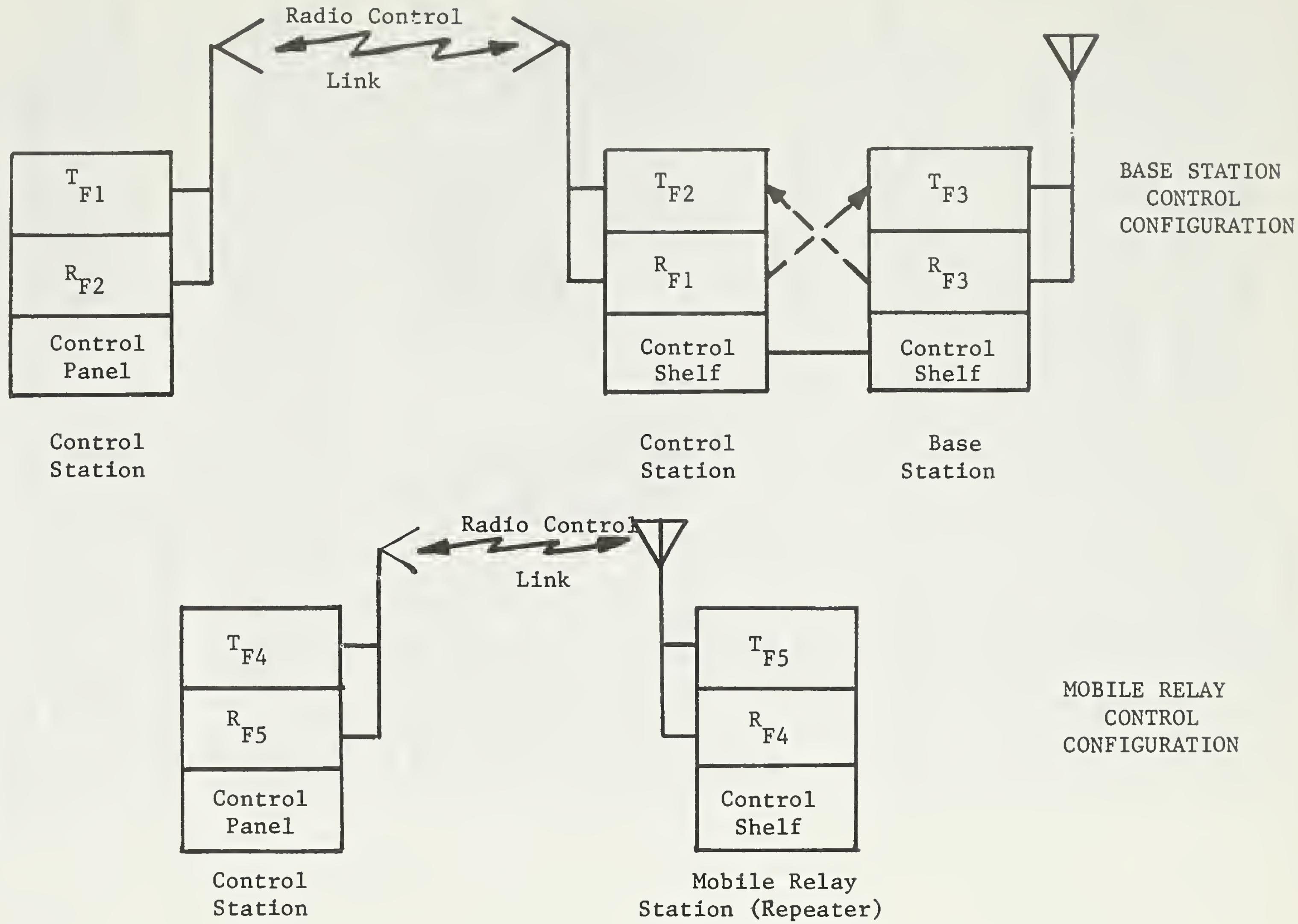


Figure II-21 Types of Control Stations

c. Mobile Relay Stations

A mobile relay station is a base station authorized primarily to retransmit automatically on a mobile service frequency communications originated by mobile stations.[4]

These stations are commonly referred to as repeaters. Repeaters, as their name implies, retransmit the signals originated by mobile stations (as well as signals originated by control stations in certain configurations). The purpose of mobile relay stations is to extend the range of mobile to mobile communications.

Mobile relay stations can also be utilized as base stations, and may be either locally or remotely controlled. Figure II-22 shows a typical mobile relay system configuration.

In the Power Radio Service mobile relay operation is permitted only on frequencies above 450 MHz.

Mobile relay systems are more vulnerable to, and more capable of creating, interference than single frequency systems. For example, skip interference could trigger a whole chain of repeater stations. For this reason it is mandatory to use a continuous coded tone signal (CTCSS) to activate the mobile relay transmitter.[5] Special coding is permitted where a user needs to select a specific mobile relay station in a system that includes many such stations. In addition, mobile relay stations must include a timer which automatically deactivates the transmitter not more than 3 minutes after its activation by a mobile unit. The timer prevents a mobile relay station from "hanging up" an entire system.

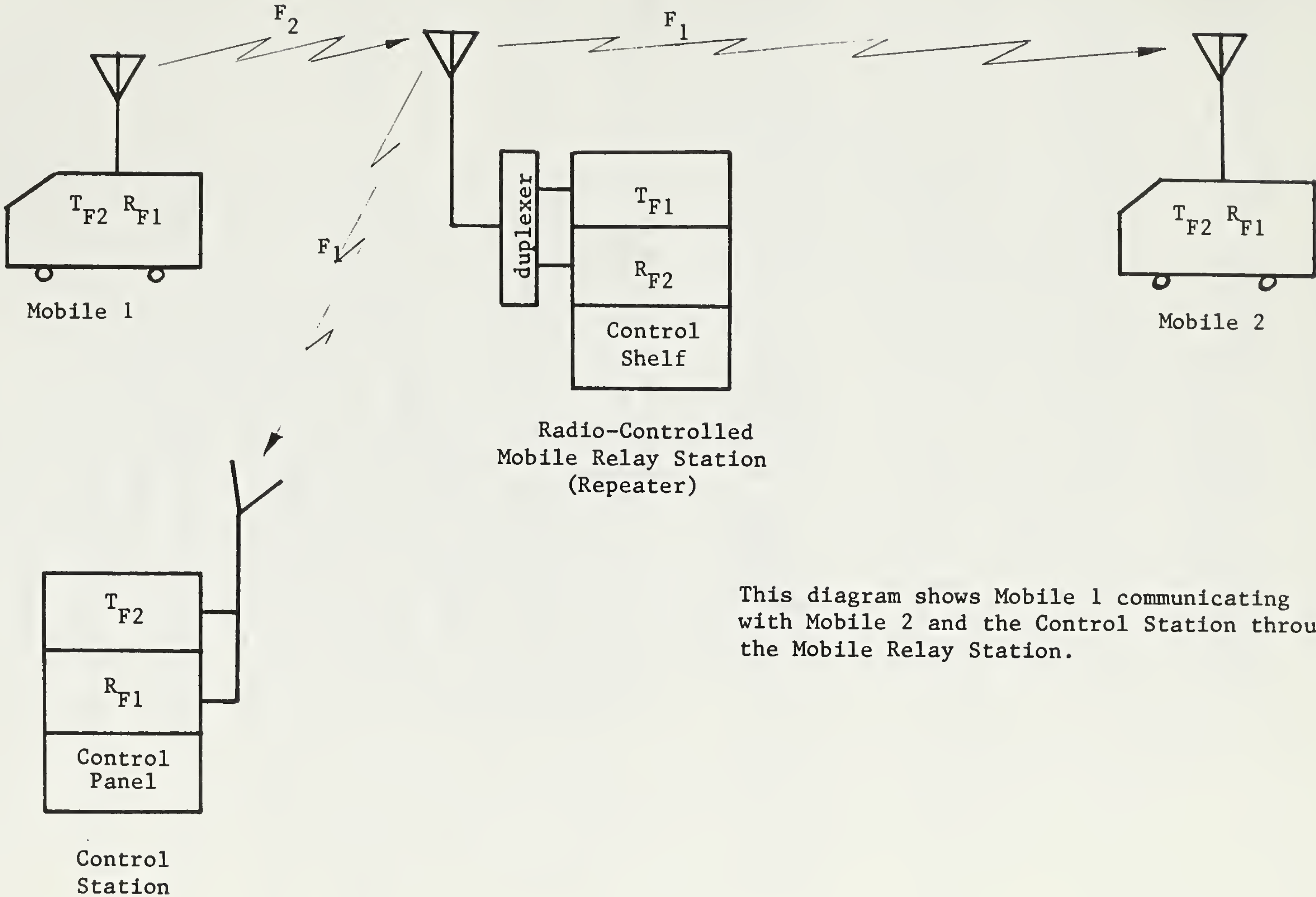
Mobile relay stations always operate with two different frequencies: one for transmitting and another for receiving. The separation between transmit and receive frequencies is usually 5 MHz in the 450-470 MHz band, 3 MHz in the 470-512 MHz and 45 MHz in the 800 MHz band.

d. Options and Accessories

A standard land station usually consists of a transmitter, receiver, power supply and control shelf. Land stations are normally supplied in five sizes and housings, depending on RF power output and location for installation. These are:

---

4. Op.cit., Paragraph 91.3
5. Op.cit., Paragraph 91.7



This diagram shows Mobile 1 communicating with Mobile 2 and the Control Station through the Mobile Relay Station.

Figure II-22 Typical Mobile Relay System

1. Desk Top. Used for low power applications and with local control. Cables enter from rear.

2. Desk Side. Used for medium power applications and with local control. Station cabinet is usually 30 inches high with front and rear door access. Cables enter from bottom or rear.

3. Wall Mount. Used for medium power applications and with local or remote control. Housing is a short rack cabinet with front door access. Rack usually can be swung outward for access to both sides of equipment. Cables enter from bottom.

4. Pole Mount. Used for medium power applications and with remote control. Principally for outdoor use. Special weatherproof short rack cabinet with front door access and swing out rack. Cables enter from bottom or rear.

5. Floor Mount (or Vertical). Used for high power applications with extended local or remote control. Housing is a standard 19 inch wide EIA rack in a 70 inch high (approximately) metal cabinet with front and rear door access. Cables enter from top, rear or bottom.

Standard land stations are supplied to operate on a nominal 117 VAC, 60 Hz, single phase input power and with FCC-specified frequency stability.

Options and accessories for land stations include (the list is by no means exhaustive):

- RF shielded cabinets
- Meters for performance monitoring
- Service microphones (for remote control stations)
- Tone or DC remote control
- High stability oscillators
- Various input power options (AC and DC)
- High sensitivity receivers
- Noise blankers
- Tone coded squelch

- 2 or 4 wire audio/control circuits
- Audio and power line protectors
- Duplexers, filters and multicouplers
- Channel scanning receivers
- Timeout timers
- Delay timers
- Adjustable RF power output
- Linear RF power amplifiers for power output up to 1 KW

There are literally thousands of possible combinations of land stations.

3. Mobile Stations

A mobile station is a [radio] station in the mobile service intended to be used while in motion or during halts at unspecified points. The term includes hand-carried and pack-carried units.[6]

a. Vehicle-Mounted Stations

Vehicle-mounted mobile stations consist of a transmitter which may range in RF power output generally from 10 to 100 watts, a receiver, a control head and a power supply. Mobile stations may be equipped to operate on one, two, four or more channels. Currently up to 12 channel units are available. The channels may be single frequency (simplex) or two frequency (duplex). Mobile stations are connected to antennas by coaxial transmission lines. Mobile stations manufactured in the United States usually operate on a push-to-talk, release-to-listen (abbreviated as PTT) basis. Other options such as listening at all times with PTT or talk and listen at all times (full duplex) as with normal telephone usage are readily supplied with equipment modifications for systems utilizing two frequency channels.

Figure II-23 illustrates the installation of a typical mobile radio in a vehicle.

Some of the more popular package forms for vehicular mobile stations are:

6. Op.cit., Paragraph 91.3

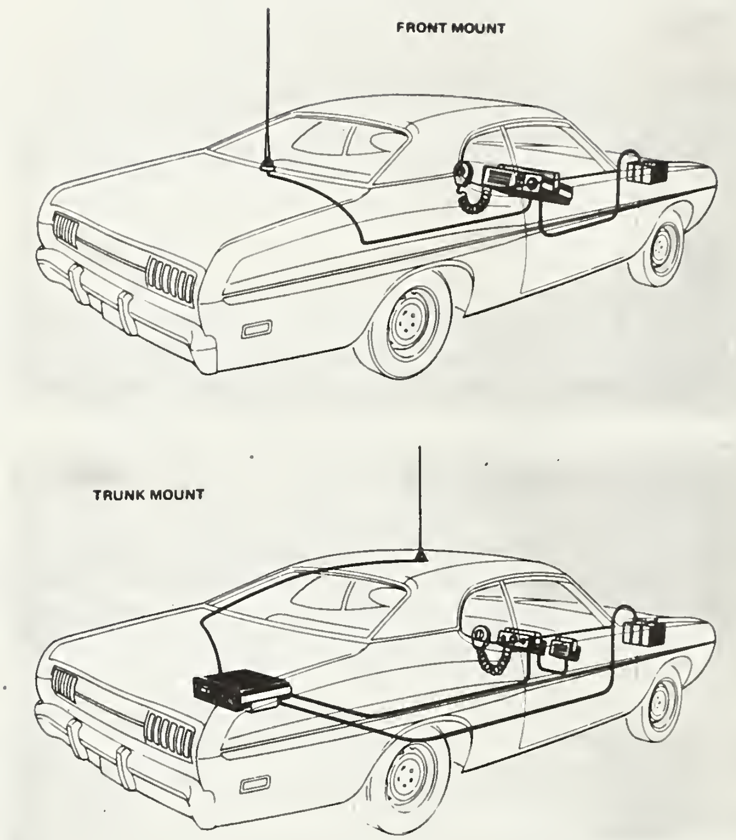


Figure II-23   Typical Mobile Radio Installation

- Trunk mount - The transmitter, receiver and power supply are mounted in the trunk. The control head, speaker and microphone are mounted under the dashboard.

- Front mount - The entire station is mounted as an integral package under the dashboard.

- Motorcycle unit - The transmitter, receiver and power supply are mounted on the rear fender. The control head, speaker and microphone are mounted on the handlebars.

- Mobile telephone - Similar to trunk mount. Control head includes a dial and handset.

There are many other combinations of radio equipment possible for vehicular application.

Mobile repeaters are special purpose vehicle-mounted radio equipment which automatically retransmit communications originated by hand-carried portable stations. They are used to extend the range of low power portable radios.

A standard vehicle-mounted mobile radio usually consists of a transmitter, receiver and power supply mounted in a metal housing; a control head, speaker and microphone mounted under the dashboard; and control and power cables. Standard mobiles are supplied to operate on a nominal 12 VDC negative ground input power with FCC-specified frequency stability.

Options and accessories for vehicle-mounted mobile stations include (the list is not exhaustive):

- Various input power options (6, 24 VDC, $\pm$ ground)

- High sensitivity receivers

- Channel scanning receivers

- Tone coded squelch

- Full duplex operation

- Multichannel operation

- Dual front end receiver

- Wide spaced transmitter or receiver

- Handset (instead of speaker/microphone)
- External speaker
- Tone signaling
- Timeout timer
- Noise blanker
- Noise suppression kit
- A variety of antennas (See Section E.7)

Mobile digital equipment accessories are also available. These include:

- Keyboards
- CRT and plasma displays
- Printers
- Facsimile terminals

b. <u>Hand-Carried Stations</u>

Hand-carried mobile stations (portables) are completely self-contained units consisting of a transmitter, a receiver, and a battery. Operating controls and antenna are mounted on the housing. Portable radios are available in sizes from ultra-miniature shirt pocket size to packset size. Currently up to 12 channels are available on the larger models. Operation of portable radios is usually push-to-talk, release-to-listen since their size generally precludes space for duplexers. The smaller portables (hand-carried type) have an RF power output from 0.1 to 6 watts. The packset type have power output up to 15 watts. The battery is usually of the Ni-Cad type which can be recharged many times. Portables can typically operate for about 8 hours between charges under typical use conditions (10-10-80 duty cycle).

Typical package forms for portable radio stations include:

- Personal portable - Completely self-contained two-way radio which can be carried and operated in one hand.
- Personal telephone - Completely self-contained radio telephone which can be carried and operated in one hand.

- Paging receiver - Pocket size receiver for tone or tone plus voice signaling (a one-way device).

- Convertible portable - Personal portable radio which is mounted in an under-dash housing. The housing includes a battery charger, audio amplifier and connections to speaker, microphone, vehicle battery and vehicular antenna.

- Packset portable - Heavy duty portable radio weighing about 10-15 lbs. with external microphone or handset and a variety of battery packs. Can also be used as a vehicular unit or land station with special accessories. Equipped with carrying handle or backpack.

A large number of accessories is available for portable radios. These include:

- A variety of antennas
  - Helical stub
  - Telescoping whip
  - Quarter wave whip
- A variety of carrying cases, straps, and belt clips
- A variety of external speakers and microphones
- Battery options
  - Ni-Cad (rechargeable)
  - Carbon zinc
  - Mercury
  - Alkaline
- Battery chargers
  - Single unit
  - Multiple unit
  - Vehicular
- Tone coded squelch
- Dual front end receivers

- High sensitivity receivers
- Multichannel operation
- Tone signaling (including DTMF)
- Channel scanning receivers

4. Control Points

FCC Rules and Regulations, Part 91, Paragraph 91.107, defines a transmitter control point as an operating position which meets all of the following conditions:

a. The position must be under the control and supervision of the licensee.

b. It is a position at which the monitoring facilities required by Part 91 are installed.

c. It is a position at which a person immediately responsible for the operation of the transmitter is stationed.

Each land station must have a control point. Additional control points may be authorized. Licensees may establish dispatch points from which messages may be transmitted under the control point supervisor's responsibility. Dispatch points do not require FCC authorization.

Each transmitter control point must be equipped with the following mandatory monitoring and control facilities:

a. A visual indication that the transmitter is in operation (pilot light or meter)

b. Aural monitoring (speaker or headset)

c. Facilities to disconnect dispatch points from transmitter

The control equipment installed at control points contains as a minimum a microphone, speaker, audio volume control, squelch control, power switch, channel selector switch, push-to-talk (PTT) switch and transmit indicator light. Other equipment commonly installed at control points includes tone signaling devices, channel status indicators, VU meter, clocks, vehicle status indicators, maps, and telephone interconnection devices (i.e. phone patch).

Many users find it convenient to install multitrack, 24 hour logging tape recorders to record the transmissions over the radio channels. Usually one track is dedicated for each

radio channel, and a special track carries time-of-day coded signals.

Figure II-24 is a block diagram illustrating typical equipment installed at a control point.

Control equipment can be either very simple or very elaborate, depending on the number of radio channels in the system, the function of the system, and the activity on the radio channels.

The simplest control equipment is usually a desk top console which includes only the essential features for control and monitoring. Figure II-25 illustrates such a console.

More elaborate control equipment is usually custom-designed for each application. Typically each operator position consists of a 60-inch wide desk with an integral turret running along the entire width of the desk. A typical configuration with dimensions is shown in Figure II-26 . The dimensions are based on human engineering principles. Consoles of this type should be specified only with the assistance of an expert.

Consoles intended for control of multichannel systems usually include provision for control of each radio channel on the radio control panel. In the panel space available it is possible to include control switches for up to 20 radio channels in each 20-inch wide console turret section.

5. Receiver Selection (Voting) Systems

Many users of mobile radio systems today are employing portable radios rather than vehicular radios. The hand-carried equipment often provides far better system utilization and increases communication efficiency for certain applications. Unfortunately, portable radios have low power and inefficient antennas (with respect to a vehicular radio) which tends to cause the talkout coverage to be much greater than the talkback coverage. To compensate for this, most personal radio systems use one or more satellite receivers and a comparator. The satellite receivers provide coverage in areas not covered by the base station receiver, and the comparator selects the best incoming signal and makes it available to the system. Two adjacent satellite receivers will provide an area of coverage that is greater than the sum of the areas covered by the individual receivers. This is due to an effect referred to as "voting system advantage".

Figure II-27 is a block diagram illustrating a typical receiver selection (voting) system.

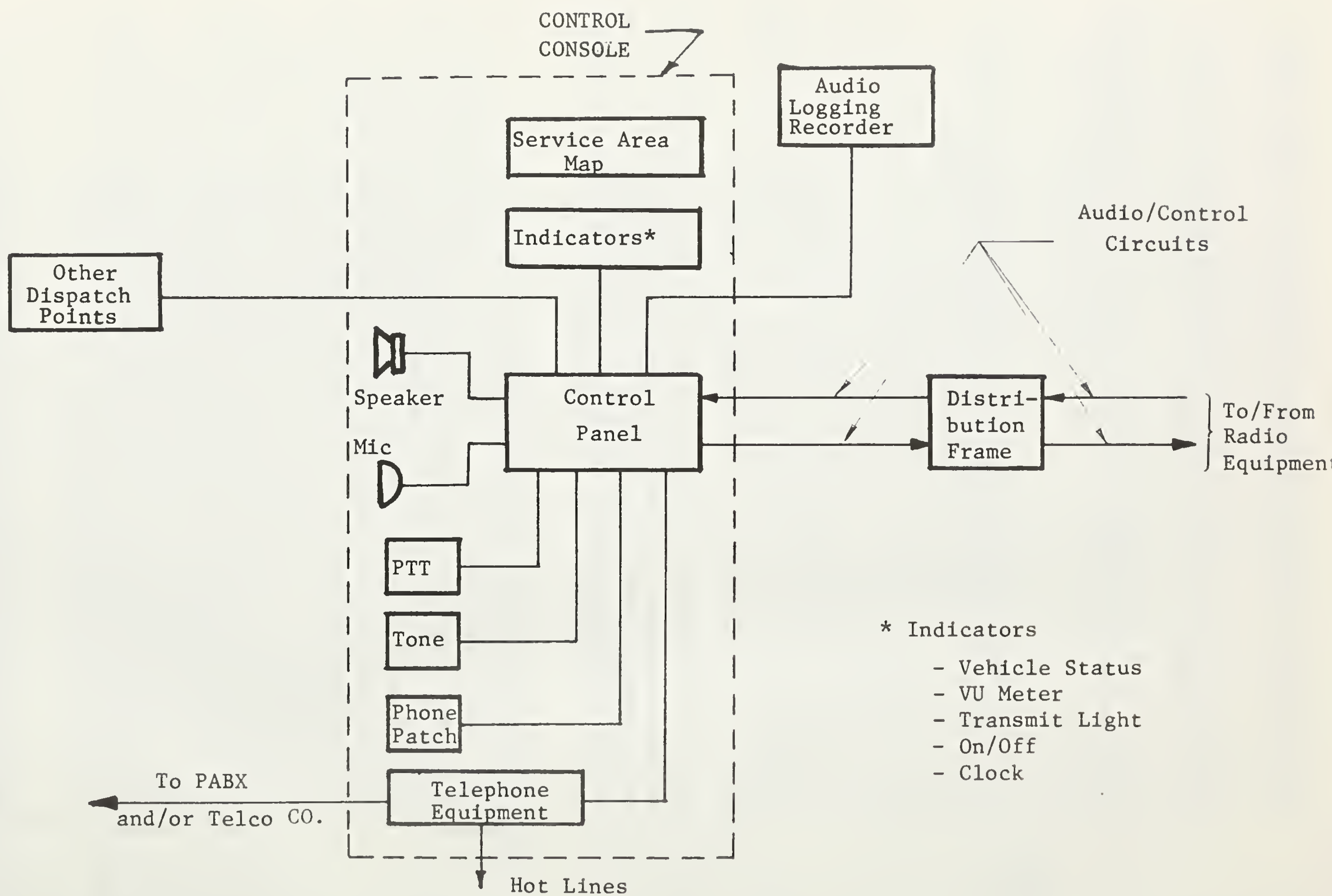


Figure II-24 Typical Control Point Equipment

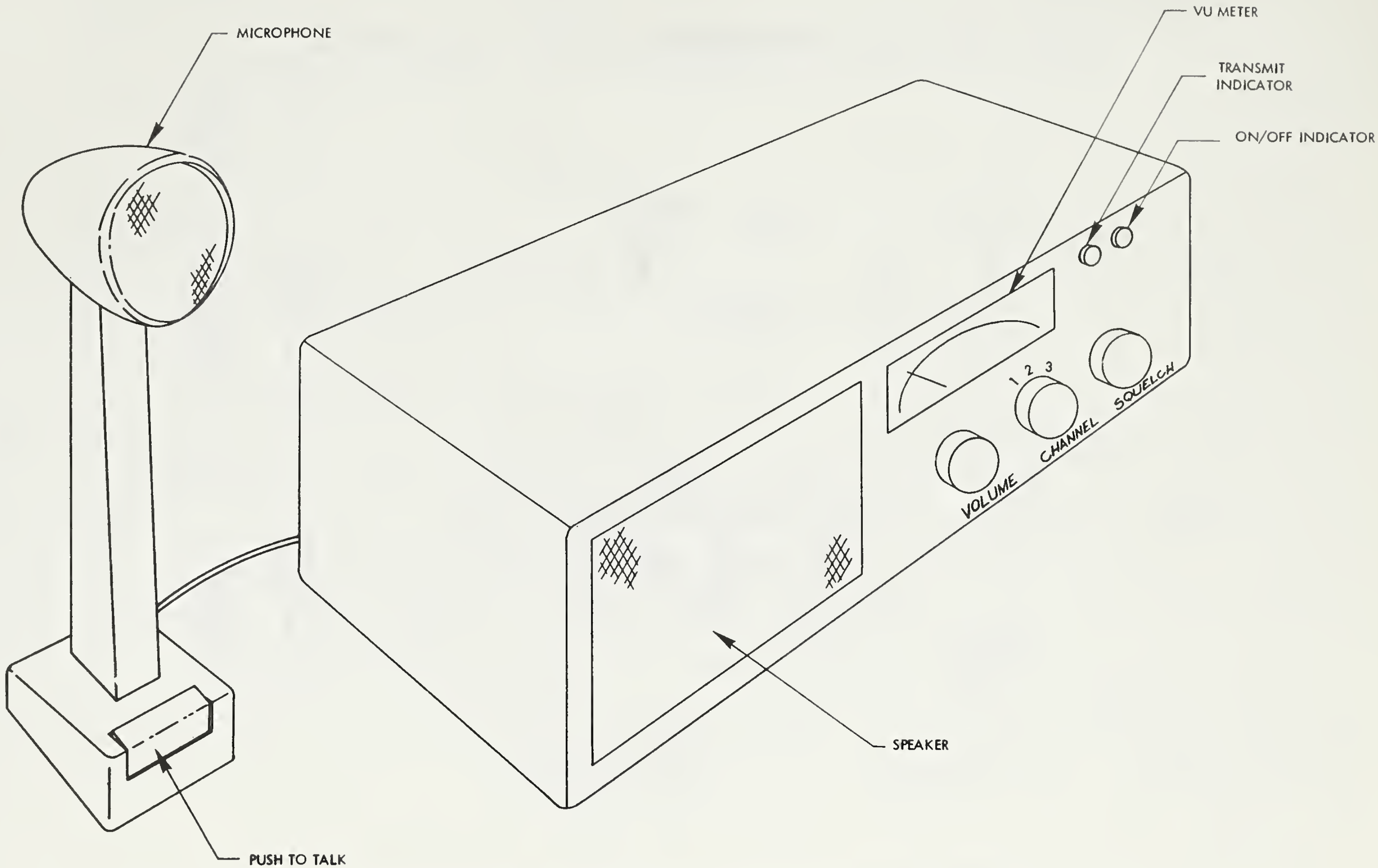


Figure II-25 Typical Desk Top Radio Control Console

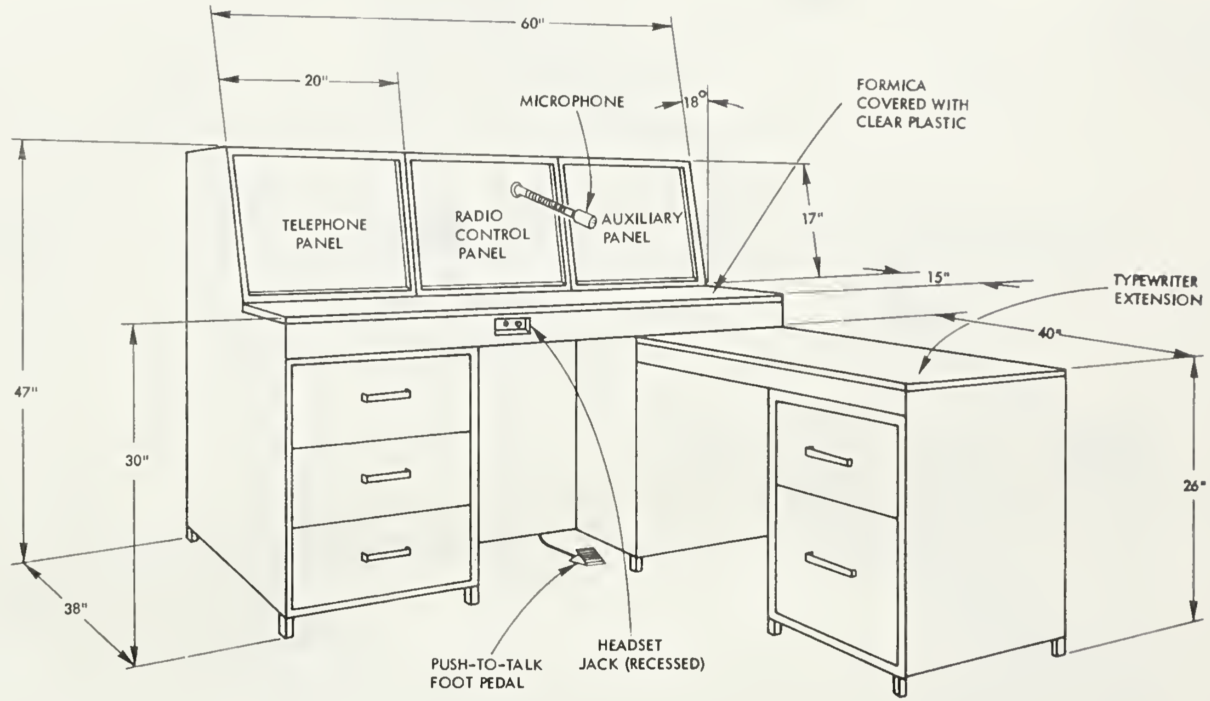


Figure II-26 Typical Custom-Designed Radio Control Console

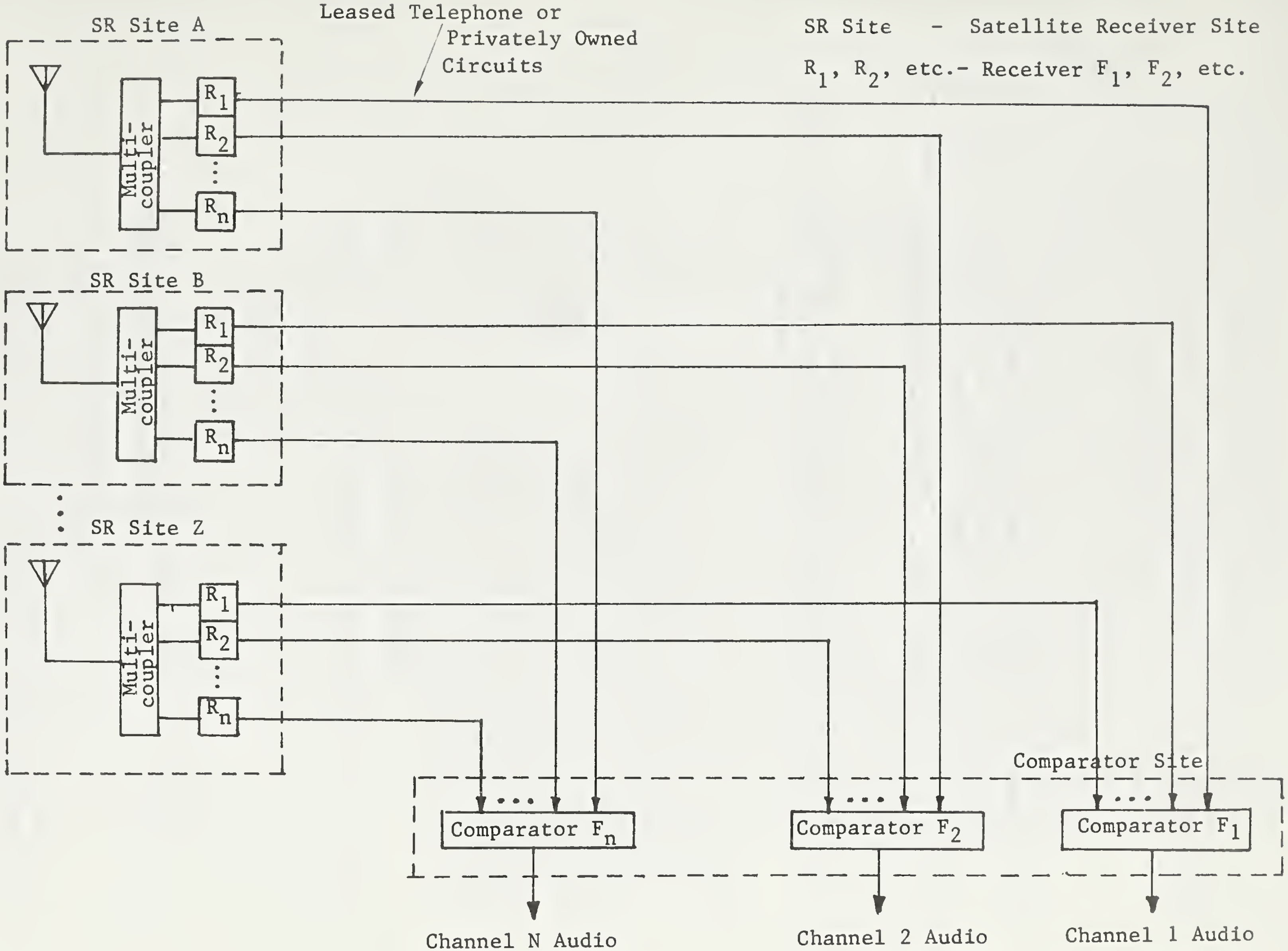


Figure II-27 Typical Receiver Selection System Block Diagram

Voting systems typically operate as follows: the signal from a portable radio is received at one or more satellite receivers. Due to differences in the radio path from portable to satellite receivers, each satellite receiver will (probably) receive a signal which is of a different signal strength from the other satellite receivers. A voltage representing the instantaneous signal strength or signal-to-noise ratio is supplied by the receiver to a tone encoder. The tone encoder generates a special tone for different increments of signal strength or quality. Each satellite receiver activated by the portable radio signal transmits the voice plus the tone signal to a comparator. The comparator instantaneously selects the best signal from those available. After initial selection the comparator continues to monitor all inputs and will reselect a better signal should the original selection deteriorate.

Voting systems can be configured to vote continuously (for voice-only systems) or to vote and hold the first selection (for digital or mixed voice/digital systems).

6. Antenna Systems for Land Stations

The antenna system of a land station consists of the antenna itself, the transmission line connecting the station to the antenna, and RF signal processing equipment. Each of these elements is discussed below.

a. Antennas

In the mobile radio services the antenna is perhaps the one equipment element that does more to determine effectiveness of operation than almost any other element. All of the other equipment elements are approaching the state of the art and are constrained by law or natural limits. Transmitter power is limited by FCC Rules; sensitivity in modern receivers is limited by noise and other characteristics of equipment currently cannot be cost-effectively improved. Only the antenna can be used to expand coverage, to increase signal strength and to improve signal-to-noise ratios.

In the land mobile services, only vertically polarized antennas are generally used because of their natural characteristics. Vertical antennas are the only feasible choice for vehicular applications. For land stations, vertical antennas are lighter in weight and easier to mount than horizontal antennas. The natural radiation pattern of vertical antennas is omnidirectional, a common requirement in the mobile services. In addition, the reflection coefficient of vertical antennas approaches zero, thus minimizing nulls caused by ground reflections - a most desirable characteristic for the mobile service.

All antennas used in land mobile applications have a characteristic impedance of 50 ohms.

Antennas for base and mobile relay stations fall into two general categories:

- Omnidirectional
- Shaped Pattern

Control stations usually employ highly directional (shaped pattern) antennas.

1. Omnidirectional Antennas

This is the most frequently used type of base or mobile relay station antenna. These antennas are the

logical choice to provide coverage to roughly circular or square service areas where the land station is located near the center of the service area.

Vertical half-wave dipoles provide an omnidirectional coverage pattern. A single half-wave dipole is considered to have unity gain (0 dB) and is the standard reference antenna. To expand omnidirectional coverage from the same location at the same antenna height and using the same transmitter power output, it is necessary to use "gain" antennas. Gain is usually accomplished by stacking two or more half-wave dipoles to form a vertical array. This arrangement compresses the radiation in the vertical plane and directs it along the horizontal plane. The horizontal pattern is still circular and the same radio energy is available, but it is directed outwards further. Two-stack dipoles have a gain of 3 dBd, and four-stack dipoles have a gain of 6 dBd with respect to a single dipole. Omnidirectional gain antennas up to 12 dBd are available, principally in the UHF band. The limitation on gain is determined largely by practical considerations of size and cost.

The most desirable mounting location for omnidirectional antennas is at the top of a tower or tall building. Practical considerations in the use of expensive towers dictate that some antennas will have to be mounted on the side of the tower. When omnidirectional antennas are side-mounted on towers, or mounted close to other antennas (as on roof-tops), lightning rods or other metal objects the coverage pattern in the horizontal plane will become distorted (i.e. the pattern will not be circular to within approximately $\pm$ 1 dB). Most antenna manufacturers can provide pattern distortion information for side mounting of antennas. In some instances, where the base station is not exactly in the center of the service area, the pattern distortion caused by a side-mounted tower can provide more serviceable coverage than a truly omnidirectional pattern.

The bandwidth of an antenna is an important consideration for the system designer, especially for multiple transmitter base and mobile relay stations. If the station antenna has proper bandwidth characteristics, one antenna can serve several transmitters and/or receivers through the use of duplexers, transmitter combiners and receiver multicouplers. The use of a single antenna provides identical patterns for all transmitters and receivers. A single antenna can be mounted at the

top of a tower to provide maximum effective coverage. Use of a single antenna reduces interference and can result in a less costly tower. In addition a broad band antenna detunes less than a narrow band antenna under similar icing conditions. Typical bandwidths of commonly available omnidirectional antennas are as follows:

Mobile Radio Band	Bandwidth
VHF Low Band	< 1 MHz
VHF High Band	6-10 MHz
UHF Bands	>20 MHz
800 MHz	>40 MHz

Land station antennas should be capable of handling all of the expected RF power output of all of the transmitters to be connected to it, with suitable reductions caused by transmission line losses and RF processing equipment insertion losses. Typical ratings are 500 watts for VHF Low Band and 250 watts for the higher frequency bands. Higher ratings can be ordered.

While the electrical characteristics (pattern, gain, bandwidth and power handling capability) determine antenna performance, mechanical characteristics are equally important since they largely determine the antenna life and serviceability. Station antennas are often mounted on tall towers where the expense of installation is often greater than the price of the antenna itself. It is important therefore that the antenna be capable of withstanding the environmental conditions of wind, ice and corrosive atmospheres without premature failure. Minimum design criteria for wind load should be 100 mph without ice and 85 mph with ½ inch of radial ice.

2. Shaped Pattern Antennas

These types of antennas are used for special applications where an omnidirectional pattern antenna would be unsuitable. Typical applications for shaped pattern antennas include:

- Coverage for odd-shaped service areas, e.g. peninsulas, elongated islands,coast lines, and rights-of-way (such as power lines, pipelines, railways and highways)

- Coverage of circular or square service areas where the land station is off-center

- Reduction or increase of radiation in a specific direction

- Point-to-point applications needed for control stations

A variety of antenna configurations is available to solve virtually any coverage, odd-shaped service area, interference, or point-to-point problem. The family of coverage patterns include:

- Unidirectional

- Bidirectional

- Offset

- Keyhole

- Cardioid

Typical horizontal radiation patterns for each of the above are shown in Figure II-28.

Unidirectional patterns are provided by Yagi, corner reflector or parabolic antennas. Figure II-29 illustrates typical unidirectional antennas. Important electrical characteristics of unidirectional antennas are bandwidth, gain, horizontal beamwidth and front-to-back ratios. Typical values for these parameters are compared in Figure II-30. Each type of antenna is effective for a different application. Careful selection is required.

Bidirectional patterns are provided by two half-wave dipoles spaced ½ wavelength apart and fed in phase or by two back-to-back Yagi antennas. The latter configuration is particularly effective for narrow right-of-way applications.

Offset patterns are provided by colinear stacking of folded dipoles on one side of a support pipe.

Keyhole patterns are provided by combining omnidirectional antennas with unidirectional antennas. Both antennas are fed in phase.

Cardioid patterns are provided by combining a reflector element with an omnidirectional antenna. This pattern is particularly effective in reducing interference in a small angle for a given direction.

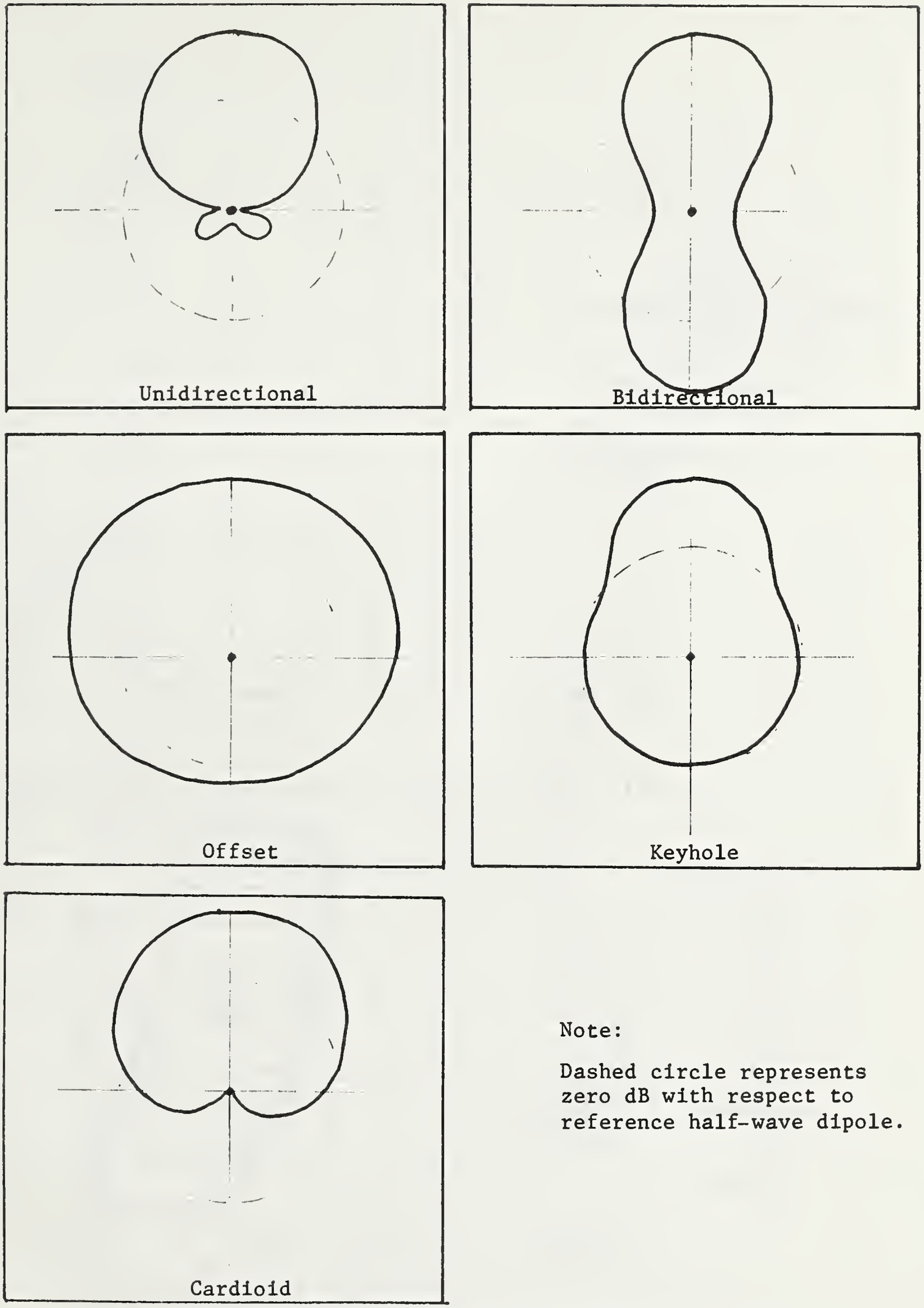


Figure II-28 Typical Horizontal Radiation Patterns for Shaped Pattern Antennas

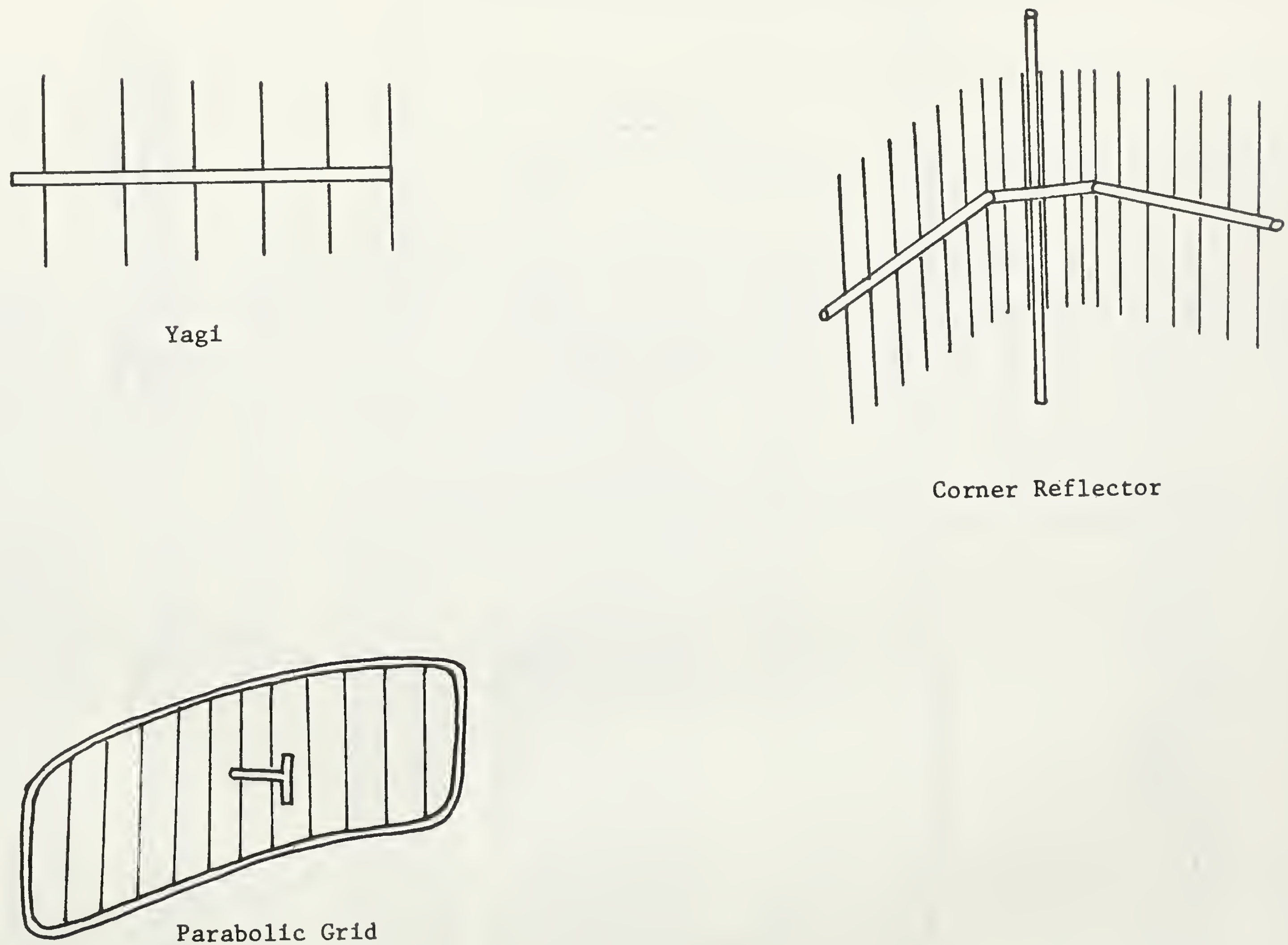


Figure II-29 Typical Unidirectional Antennas

	YAGI				CORNER REFLECTOR				PARABOLIC			
Band	G (dBd)	HBW (degrees)	BW (MHz)	FBR (dB)	G (dBd)	HBW (degrees)	BW (MHz)	FBR (dB)	G (dBi)	HBW (degrees)	BW (MHz)	FBR (dB)
VHF Low Band (30-50 MHz)	7-15	76	1	22								
VHF High Band (150-174 MHz)	7-16	60	3-10	15	8-15	60	25	30				
UHF Band (450-470 MHz)	10-16	60	20	18	8-18	40	20	25				
800 MHz Band									15-20	10-20	40	20-30

G - Gain
HBW - Horizontal beamwidth at half power points
BW - Bandwidth
FBR - Front to back ratio

Figure II-30 Typical Electrical Performance Parameters for Unidirectional Antennas

b. Transmission Lines

The transmission line is the means for connecting a transmitter or receiver to an antenna. The most practical type of transmission line at frequencies below 1000 MHz is the coaxial cable wherein one conductor is contained within the other. The inner conductor is located concentrically within the outer conductor, and the two are separated by a dielectric insulating material.

1. Solid Dielectric Cables

Solid dielectric coaxial cables are insulated with teflon or polyethylene, and the outer conductor is a braided copper sheath. The inner conductor is often of stranded untinned copper. The cable is covered with a vinyl resin jacket. Solid dielectric coaxial cable is used when it is to be handled and flexed frequently. The velocity of propagation is 66% of the velocity of radio waves in space. The loss is higher than foam or air dielectric coaxial cables. Typical designators for 50 ohm impedance, solid dielectric coaxial cables are RG 213/U or RG 8/U, and RG 218/U or RG 17/U.

2. Foam Dielectric Cables

Foam dielectric cable consists of a high-conductivity copper inner conductor with a cellular polyethylene foam dielectric type of insulation between the inner and outer conductor. The outer conductor consists of a high-strength solid aluminum sheath. Foam dielectric coaxial cable is used when the cable runs are long and permanently installed.

3. Air Dielectric Coaxial Cables

Air dielectric cables use a chemically dried and pressurized gas or air as dielectric along with teflon or polyethylene spacers to provide concentric alignment between the inner and outer conductors. The velocity factor for pressurized cables is from 86% to 92% depending on construction differences in design and manufacture. The coaxial cable loss is 10% to 11% less than foam insulated cable of equivalent size. Pressurized coaxial cable requires dehydrators, pressure pumps and low pressure alarms to ensure reliable operation.

Figure II-31 shows coaxial cable attenuation for popular sizes of solid, foam and air dielectric coaxial cables used in the mobile radio service. This graph is handy for comparing the loss in dB/100 feet between several types and sizes of coaxial cables.

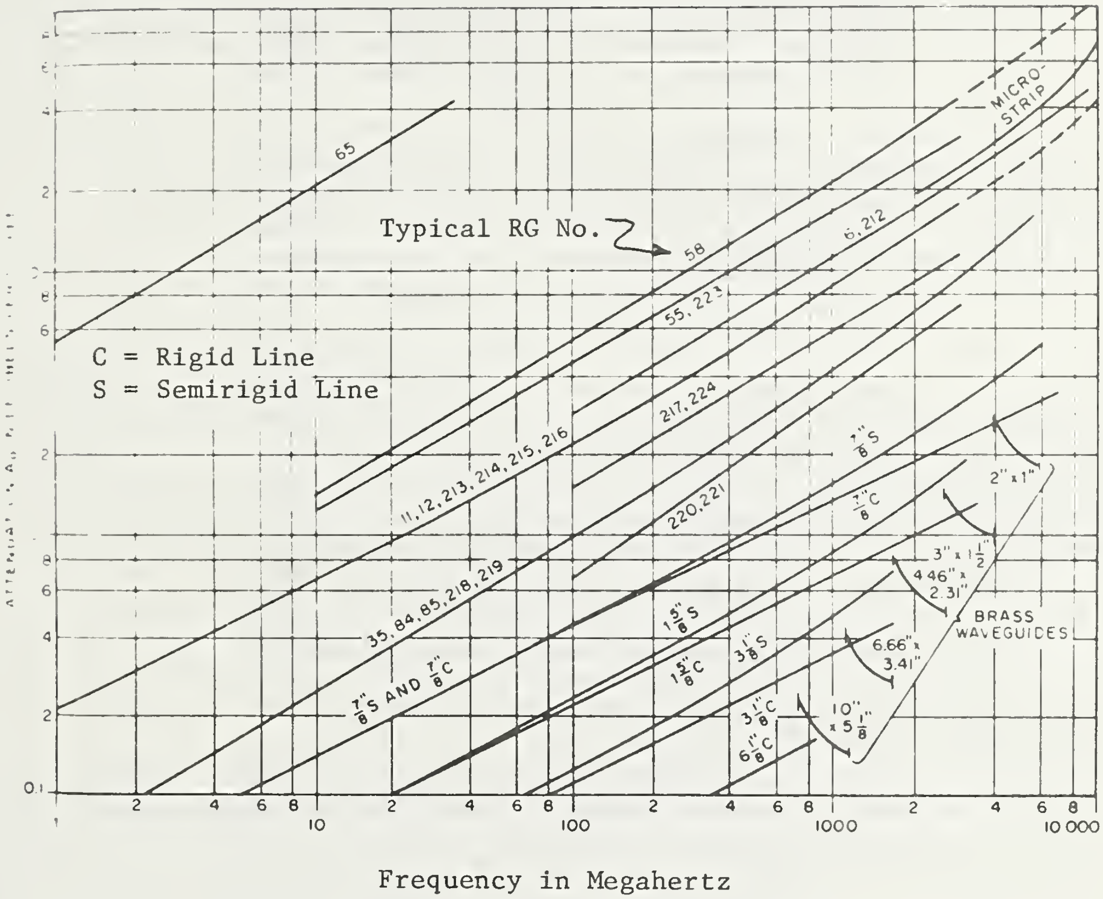


Figure II-31 Coaxial Cable Attenuation Curves

c. <u>RF Signal Processing</u>

The term RF signal processing is applied to equipment that is used to enable a mobile radio circuit to function effectively in a radio environment crowded with other nearby radio circuits. Some items of equipment are used to reduce interference, and other items are used to enable more than one transmitter or receiver to be connected to one antenna. Some items of signal processing equipment allow a transmitter and receiver to be connected to the same antenna for duplex operation. The following signal processing devices are discussed in the order listed below:

- Isolators
- Harmonic filters
- Bandpass filters
- Band rejection filters
- Crystal filters
- Duplexers
- Transmitters combiners
- Receiver multicouplers
- Interference cancellation systems

1. <u>Isolators</u>

The isolator is a ferrite device used to reduce interference caused by transmitter intermodulation. The isolator is actually a circulator with a resistive load connected to the load port. A circulator is a unique device which allows RF power to flow in one direction only. Power entering the input port goes to the output port with a small loss, typically 0.5 dB. Power entering the output port goes to the load port, where it is dissipated in the resistive load. Transmitter intermodulation interference is caused when two or more signals of different frequencies are mixed in the non-linear output RF amplifier of a transmitter. The mixing generates a large number of new frequencies (intermodulation products). When the isolator is used between the transmitter and antenna, the RF power from the transmitter goes through the isolator to the antenna with very little insertion loss, but RF power entering the antenna toward the transmitter is directed to the resis-

tive load where the RF power is dissipated. The isolation in this direction is typically 25 dB. Sometimes two isolators are used in series to increase isolation.

2. Harmonic Filters

Harmonic filters can be installed between the transmitter and the antenna. These are low pass filters having a 3 dB cut-off point approximately 10% above the transmitting frequency. When many transmitters are crowded into one site, additional harmonic filtering may be required.

If isolators are used for reduction of transmitter intermodulation interference, it is necessary to use a harmonic filter at the output of the isolator. The isolator is a non-linear device and tends to generate harmonics as the transmitter RF power passes through the isolator.

3. Bandpass Filters

Bandpass filters are of two basic types, the lumped LC filter and the tuned cavity filter. These filters are used to reduce transmitter noise, intermodulation interference, and receiver desensitization. Cavity filters have a higher Q than lumped LC filters and therefore a narrower bandpass capability. Both types of filters can be connected in series with more filters providing a narrower bandpass but greater insertion loss. The bandpass cavity filter is particularly effective when the interfering and desired frequencies are separated by 2 MHz or more. Bandpass filters are connected in series between the transmitter and the coaxial cable leading to the antenna. Since a cavity filter must be one-quarter wavelength long, the use of this type of filter is usually limited to frequencies above 30 MHz.

4. Band Rejection Filters

The band rejection (notch) filter or stop band filter may be a lumped LC circuit or a cavity filter. The cavity filter provides sharper attenuation curves because of the high Q of this device. The sharp attenuation curves allow the band rejection filter to be used for frequencies a minimum of 150 KHz from the transmit frequency. More than one band rejection filter may be connected to the same transmission line as a means of increasing the attenuation at the rejection frequency. However, the insertion loss increases in proportion to

the number of filters connected to the antenna system. Band rejection filters are connected in parallel with the transmission line.

5. Crystal Filters

Crystal filters are extremely narrow bandpass devices using piezo electric principles. The bandpass of this type of filter is narrow enough to prevent receiver desensitization caused by transmitters operating on adjacent channels. These filters operate at the incoming RF channel frequency. This means that the crystals are thin and fragile and easily damaged by RF power entering the filter through the antenna system from nearby transmitters, and they are subject to damage from nearby lightning strikes. For these reasons crystal filters have had limited application.

6. Duplexers

Duplex operation of transmitters and receivers can be accomplished using separate antennas. The isolation required to prevent the transmitter from desensitizing the receiver can be obtained with sufficient vertical or horizontal separation. However, if antenna space is limited, filter devices can be arranged to provide the necessary isolation.

Bandpass duplexers are used where the frequency separation between receive and transmit frequencies is 3 MHz or greater. These duplexers consist of quarter-wave coaxial cavity filters.

Band reject duplexers are made up of coaxial cavity filters used in the band reject mode. These filters are used where the separation between transmit and receive frequencies is more than 500 KHz and less than 3 MHz. This type of filter requires from 6 to 8 cavities and provides from 80 to 110 dB isolation.

Band reject helical cavity filters are more compact, but with low Q compared to coaxial cavity filters. The helical filters can be made small enough for mobile use if the frequency separation is 5 MHz or more.

One other type of device offers considerable promise in the mobile radio field as a duplexer, if the price can be reduced and the operation improved. This device is the interference cancellation system. Prototypes of this device can provide 60 dB of isolation between the transmitter and receiver at most fre-

quency separations, including the transmit frequency. A description of the interference cancellation equipment is provided at the end of this section.

7. Combiners

Combiners are devices which allow two or more radio systems to operate on the same antenna and transmission line. The systems may be all transmitters, all receivers or a combination of transmitters and receivers. When two or more transmitters are to be used on a single antenna, the primary concern is transmitter intermodulation products. In transmitter intermodulation, a signal from transmitter #1 reaches the final amplifier of transmitter #2 and mixes with the RF energy in the final amplifier of transmitter #2. A similar mixing of transmitter #2 signals in the final of transmitter #1 also occurs. This results in interfering signals at intervals equal to the frequency difference between the two transmitters. These interfering signals appear on either side of the two transmit frequencies and diminish in intensity as the frequency separation from the transmit frequencies increases. Combiners connecting transmitters and receivers to the same antenna have isolation requirements similar to that of duplexers. Transmitter noise, receiver desensitization and transmitter intermodulation must all be reduced to a non-interfering level. There are two general categories of combiners: ferrite and cavity type.

a. Ferrite Combiners

Ferrite combiners are used to connect two or more transmitters to a single antenna. This type of combiner is used when the transmitter frequencies are very close; from adjacent channels to 500 KHz. Hybrids and isolators are the main ferrite devices used in these combiners. The hybrid can combine the signals from two transmitters and provide 25 to 40 dB isolation between them.

Figure II-32 is the schematic of a hybrid. The signal connected to port 1 splits equally between ports 3 and 4. The signal connected to port 2 is split equally between ports 3 and 4; therefore, half the power from a transmitter connected to port 1 and half the power from a transmitter connected to port 2 will exit at port 4. The remaining power from each transmitter will exit at port 3. This results in a 3 dB loss in signal power from each transmitter. The total loss, including insertion loss, is approximately

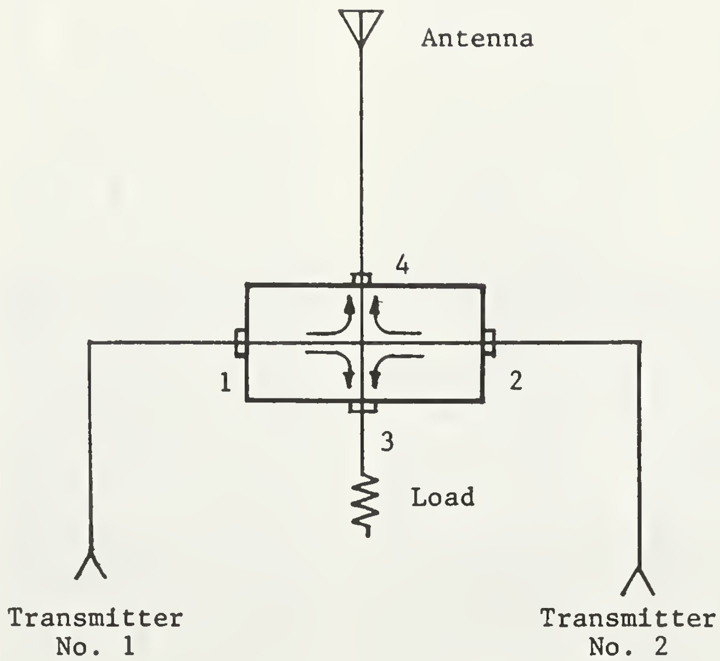


Figure II-32 Schematic of Hybrid

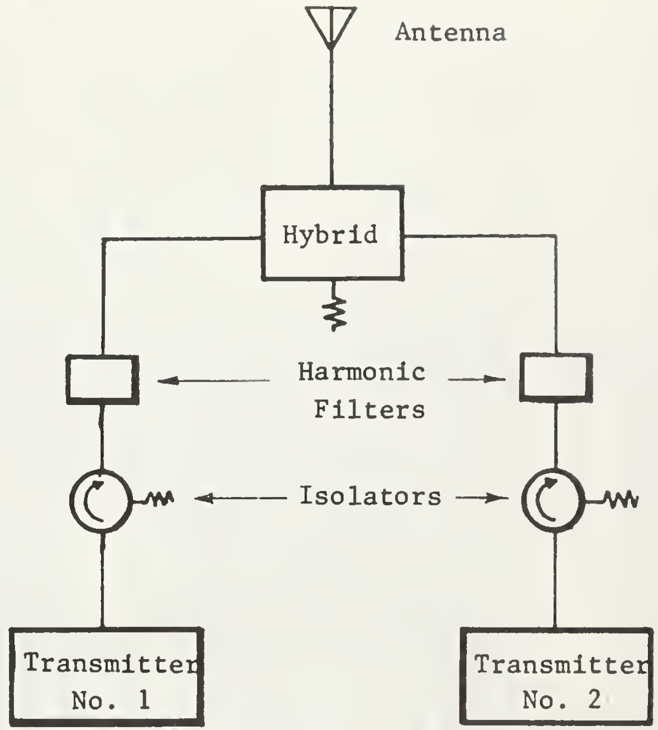


Figure II-33 Combiner for Two Transmitters Using Ferrite Devices

4 dB. A 4 dB drop in signal strength reduces coverage unless the transmitter power is increased or a higher gain antenna is used. The two transmitter ferrite type of combiner is shown in Figure II-33.

The hybrid has a 0.5 dB insertion loss in addition to the 3 dB power loss due to signal splitting. Each isolator is required to further reduce transmitter intermodulation products. This device adds another 0.5 dB to the antenna system loss.

b. Cavity Type Combiners

The cavity type combiner is less lossy than the ferrite type. The basic difference is that the cavity type combiner does not split the power. These cavities are used when the frequency separation between channels is approximately 150 KHz on the low-band, 500 KHz on the 160 MHz band and 1 MHz on the 460 MHz band. The insertion loss for the cavity filters varies from 0.5 dB to 3.0 dB per unit, depending on the width of the bandpass desired. In order to have a narrow bandpass at minimum loss several cavities must be connected in series. The insertion or loop loss for each cavity is set at 0.5 dB. This results in a rather wide bandpass for each unit but the selectivity of each unit adds to the other so that the result is a narrow bandpass filter. The cavity filters can be arranged as bandpass or band reject filters, depending on the desired results and the number of frequencies to be combined. The band reject filter arrangement provides greater isolation but requires an excessive number of cavities when the number of channels to be combined goes above three. Bandpass/band reject filter combinations can be used to obtain good isolation at minimum insertion loss when more than three channels must be combined. The nominal insertion loss for a three channel filter arrangement is approximately 2.5 dB.

8. Receiver Multicouplers

The term "multicoupler" is used in connection with any device designed to couple multiple receivers to one antenna. This device usually consists of a low noise amplifier driving from 2 to 20 or more isolated outputs for receivers. This can reduce the number of antennas and antenna coaxial cable feeders from 20 to 1 or more in the case of full utilization of the equipment.

The use of the multicoupler reduces antenna horizontal pattern distortion, which is caused by signal coupling and reradiation from adjacent antennas.

It is important that the receiver multicoupler not reduce the overall sensitivity of the system. Any increase in noise or any signal attenuation which is caused by the multicoupler will degrade the system performance.

9. Interference Cancellation System

The Interference Cancellation System (ICS) cancels interferences from colocated transmitters by tapping a small portion of the signal, called the reference signal, from the offending transmitter and adaptively processing this signal so that it is equal in amplitude and opposite in phase from the interfering signal. When the interfering signal and the processed reference signal are combined, cancellation results. Cancellation is maintained by employing adaptive feedback to minimize the power level of the cancelled interfering signal. The feedback scheme consists of diverting a small fraction of the cancelled interfering signal from the ICS receiver unit output and correlating it with the reference signal. The DC voltages resulting from this correlation drive the circuitry which adjusts the amplitude and phase of the reference signal.

Figure II-34 shows a block diagram of the ICS. The transmitter unit consists of a 12 dB directional coupler which diverts 1/16 of the transmitter power to be used as a reference signal by the receiver unit. The insertion loss through the directional coupler from the transmitter to its antenna is less than 0.7 dB.

The ICS receiver unit consists of a summer, a 4.5 dB directional coupler, a 20 dB directional coupler, a distribution amplifier, a splitter, an error processor, a power supply, a line filter and one channel module for each transmitter signal to be cancelled. The receiver unit shows a loss of about 5 dB at the single receiver connection but shows a slight gain when the multicoupler amplifier is used.

When the ICS is in operation, it cancels only the signal entering through the reference port. If the colocated transmitter which is connected to the reference port is received at the receiver unit antenna connection at 15 dBm, it will appear at the receiver unit output connection at approximately -65 dBm. If another transmitter is transmitting on the same frequency at a distance of

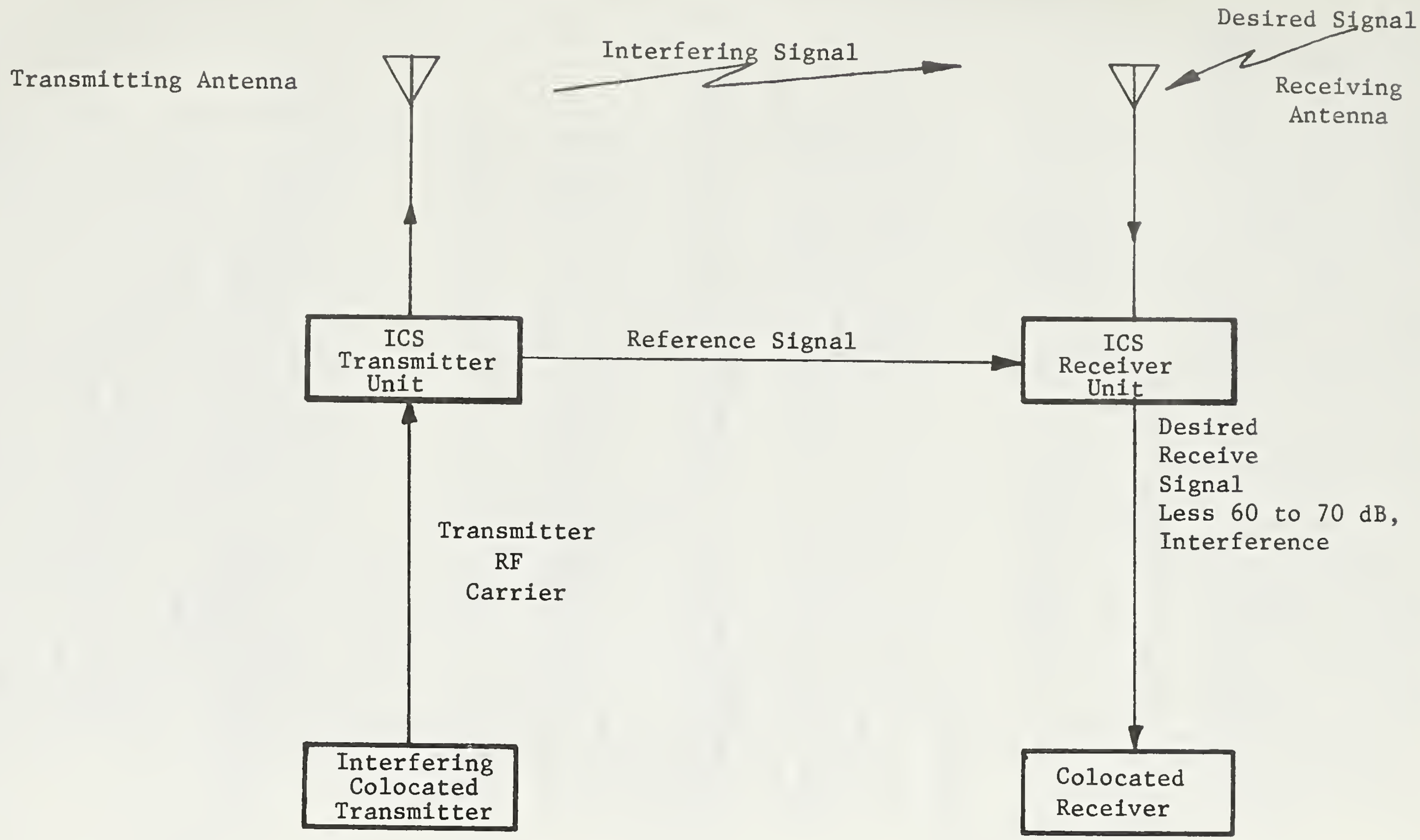


Figure II-34 Simplified Block Diagram of One Channel of an ICS

3 to 5 miles away, it will be heard clearly above the colocated transmitter. Considering the additional attenuation of the receiver for adjacent channel operation, there is very little chance that the colocated transmitter will cause adjacent channel interference. Only prototypes have been tested thus far. However, if development continues, working models of the ICS will do much to reduce interference from colocated transmitters.

7. Antenna Systems For Mobile Stations

The antenna system of a mobile station consists of the antenna itself, the transmission line connecting the station to the antenna, and RF signal processing equipment. Each of these elements is discussed below.

a. Antennas

Mobile stations require an efficient antenna which is capable of withstanding the severe mechanical forces and environmental conditions imposed in use. There are also size and convenience factors which must be considered in the design of mobile antennas.

As in the case of land stations, vertically polarized antennas are almost universally used by mobile stations.

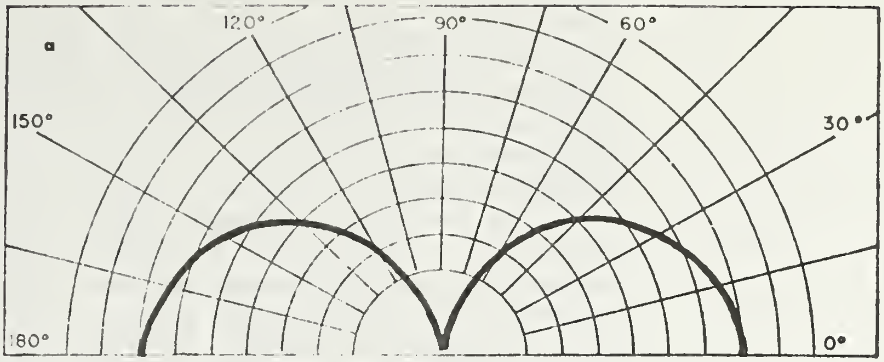
Because of the random orientation of the vehicle with respect to the land station, omnidirectional antennas are always utilized by mobile stations.

There are three general types of mobile antennas. These are: vertical whip, low profile, and disguised.

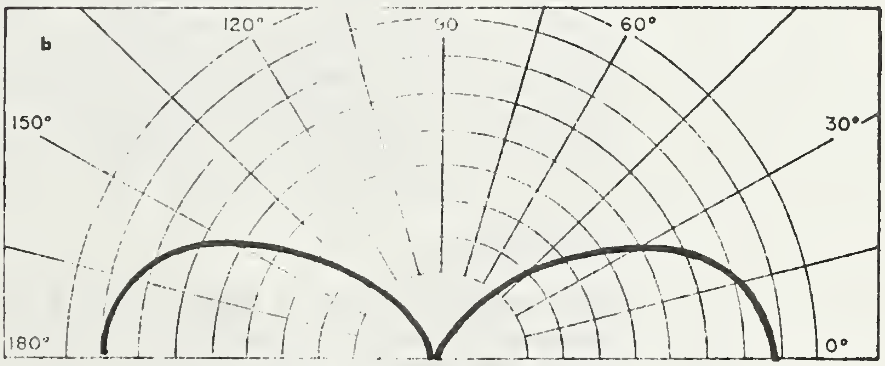
1. Vertical Whips

Vertical whips are by far the most common type of antenna used in vehicular applications. They provide a natural omnidirectional pattern and are convenient and easy to install.

Vertical whip antennas are supplied as either 1/2, 1/4 or 5/8 wavelength, the most common being the 1/4 and 5/8 wavelength. The 1/4 wavelength antenna is considered the standard reference mobile antenna and is considered to have unity gain (0 dB). The 5/8 wavelength antenna has 3 dB gain over a 1/4 wavelength antenna. Figure II-35 illustrates typical vertical radiation patterns for the three types of antennas.

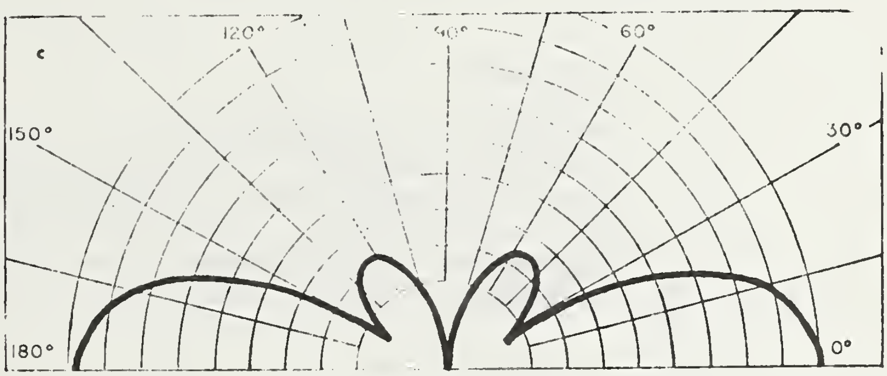


Half Wavelength



Quarter Wavelength

(Reference Antenna - 0 dB Gain)



Five-Eighths Wavelength

Figure II-35 Vertical Radiation Patterns for Vertical Whip Antennas

Vertical whip 1/4 and 5/8 wavelength antennas are fairly long, particularly in the VHF Low Band and VHF High Band. Figure II-36 is a table listing the length of vertical whip antennas for the various mobile service frequency bands. To reduce the physical length of these vertical antennas, loading coils are widely used. Some antennas use base loading, others center loading coils. A decrease in length up to 2:1 permits mounting antennas on more convenient locations (e.g. trunk lid or roof top) without undue exposure to damage. Loading coils used for shortening antenna length reduce bandwidth, and greater care must be taken in tuning and loading the antenna to obtain maximum efficiency.

Vertical 1/4 and 5/8 wavelength antennas require a ground plane for maximum radiation efficiency. This is usually accomplished by mounting antennas on a horizontal metal surface such as a trunk lid or roof top. Considerable pattern distortion results from any antenna mounting location other than the roof top.

2. Low Profile

Tall vehicles such as buses, trucks and trains are particularly susceptible to antenna damage. There are several models of low profile antennas available for this application. Gain for this type of antenna is usually 0 dB and the pattern is roughly omnidirectional.

3. Disguised

For special applications where the user may want to conceal his mobile radio capability there are several types of disguised antennas. Some can be supplied resembling standard AM/FM broadcast band antennas, others are constructed as part of a side mounted rear-view mirror.

	Wavelength		Antenna Type						Wavelength
	λ		λ/2		λ/4		5λ/8		λ
Freq. (MHz)	ft.	in.	ft.	in.	ft.	in.	ft.	in.	meters
30	32.8	393.6	16.4	196.8	8.2	98.4	20.5	246.0	10.0
50	19.7	236.2	9.8	118.1	4.9	59.0	12.3	147.6	6.0
160	6.1	73.8	3.1	36.9	1.5	18.4	3.8	46.1	1.87
460	2.1	25.7	1.1	12.8	0.5	6.4	1.3	16.0	0.65
830	1.2	14.2	0.6	7.1	0.3	3.6	0.7	8.9	0.36

$$\lambda_{ft} = \frac{984}{F_{MHz}}$$

$$\lambda_{in} = \frac{11808}{F_{MHz}}$$

$$\lambda_{m} = \frac{299.92}{F_{MHz}}$$

Figure II-36 Wavelengths and Typical Vehicular Antenna Dimensions for Each Mobile Radio Frequency Band

b. Transmission Lines

In mobile stations transmission lines are small diameter coaxial cables. RG-58/U is the most common type used.

c. RF Signal Processing Equipment

In mobile stations, the only RF signal processing equipment commonly used is the duplexer. Mobile duplexers are usually of the band-reject configuration and utilize helical resonators or coaxial cavities. Most mobile duplexers are designed to operate with transmit and receive frequencies separated by 5 MHz or more and can handle transmitter power outputs of up to 100 watts.

8. Power Systems

A constant and stable source of electric power is a basic requirement for the operation of mobile radio systems. This section will discuss some of the technical factors associated with power systems for land, mobile and portable radio equipment.

a. Land Station Power Systems

1. Commercial Power

The majority of land stations (i.e. base, control and mobile relay stations) in the United States utilize power supplied by the local commercial or public utility. Although many utilization voltages are available, the most common supply is 208 volts, three phase, wye connected, 60 Hz and/or 120 volts, single phase, 60 Hz.

Most mobile radio land stations work directly from the 120 volt utility line. Manufacturers furnish a DC power supply contained within the radio equipment rack which converts the prime AC voltage to the DC voltages required by the transmitter and receiver sections and the control shelf.

2. Locally Generated Prime Power

Radio sites installed on remote mountain tops with poor access roads or in other difficult areas which cannot be economically served by commercial power require a locally generated and reliable source of prime power. A variety of both conventional and unconventional means are available for this type of site including:

- Engine-generator bank (fossil fuel)
- Thermoelectric generators
- Solar arrays
- Wind generators

The system selected is usually dictated by load requirements and cost trade-off. Each of these systems is discussed below.

a. Engine-Generator Bank

Remote stations having a heavy critical load (generally above 5 kW) can be equipped with a bank of two or more fossil fuel engine-generators, one of which is on line continuously. Typically, three identical generators are installed, one is on line, one is on standby service and the third is available for scheduled maintenance. Each generator is capable of supplying the entire station load. Sites configured with this type of prime power source require relatively good access roads and large fuel tanks.

b. Thermoelectric Generators

This type of prime power source is selected when demand load is low (under 1 kW), access roads are difficult and maintenance cannot be performed easily. TEG's are highly reliable generators which utilize LPG. They have no moving parts. It is desirable to include an 8-hour battery bank on float charge for critical station loads.

c. Solar Arrays

This type of prime power source is usually selected for very remote sites having a very low (under 1 kW) demand load and where solar energy is abundant. Solar arrays are expensive but highly reliable and require almost no maintenance. It is necessary to include a battery bank on float charge to compensate for night time demand and cloudy days. The battery bank is sized in accordance with local historical data on solar energy and the expected duty cycle of the radio equipment.

d. Wind Generators

This type of generator can supply prime power only in sites having consistent wind. Wind generators are rarely used for radio sites.

3. Standby DC Power

In some special cases, land stations are designed to operate from a common DC power plant. This common DC power system consists of storage batteries having an 8-hour or longer reserve, chargers and rectifiers. The rectifier/charger converts the AC supply voltage to DC and supplies energy to the battery so that it remains in a fully charged condition during normal operation. This action is called "floating", and is accomplished by connecting the battery in parallel with the output of the rectifier/charger. This type of power system is sometimes used for low power (below 90 watts RF output) land stations requiring "no-break" operation or very high reliability. The most common application, however, is for satellite receiver sites equipped only with receivers.

Some manufacturers offer radio equipment capable of operating on both 120 VAC and 12 VDC. The radio equipment is provided with a standby battery and a transfer/charging panel. During normal operation the battery receives a trickle charge. When AC power fails the radio is automatically transferred to DC operation. Upon restoration of AC power the radio is automatically transferred back to AC operation. This option is generally available with land stations rated at 90 watts RF power output (on AC) or less. During DC operation the station operates at a reduced RF power output, usually the "driver level".

4. Standby AC Power

Although electric power supplied by most commercial or public utility companies in the United States is usually very reliable, it is subject to interruptions. Transmission lines may be damaged by storms, buried lines may be cut by construction activity, lightning may strike transformers, and switches and insulators may deteriorate and fail.

Power industry mobile radio systems which utilize a commercial system of primary power should have a backup or standby source of AC power. Most mobile radio systems can tolerate a few seconds of outage while the

standby AC source starts up and assumes the load. "No-break" or UPS operation is rarely required and will not be discussed.

Standby AC power for radio sites is usually provided by prime mover internal combination engines. These are available in various sizes and fuel types.

In selecting the correct standby generator there are three major factors to consider. These are:

- Capacity (or size)
- Fuel
- Cooling system

Each of these is discussed below.

a. Capacity

This is the most important factor. A careful study should be made to determine exactly the load and the degree of service it is desirable to maintain during a power outage. It is normal practice when sizing a generator to segregate the total station load into a "non-critical" and "critical" and to serve only the critical loads with the standby generator. The critical load at a radio site usually includes: radio equipment, chargers and rectifiers, tower lights, and a few of the interior lights and outlets. The heating and airconditioning loads are normally considered non-critical.

It is desirable to adopt a long-range view and allow a margin for additional future critical loads. An additional 50% capacity is a useful rule of thumb.

An important factor is the elevation above mean sea level of the radio site. Generators should be derated 4% for each 1,000 feet above sea level.

b. Fuel

Before the engine can be selected, careful consideration must be given to selecting the proper type of fuel. Fuel selection is important because each has individual characteristics which may be advantageous for one application while disadvantageous for another. The factors which may in-

fluence the choice of one type of fuel over another are:

- Initial cost of the generator set
- Maintenance costs
- Availability of the various fuels
- Local fuel storage regulations
- Performance requirements

The fuel options are: gasoline, gaseous (gas) and diesel.

Gasoline and gas generators have a lower initial cost than the same size diesel unit -- as much as 50% less in the smaller capacity units. The price difference is less significant with high capacity units.

Gasoline is difficult to store over extended periods of time; special precautions must be taken in storage, and the quantity kept on hand should be minimal.

Gasoline engines start quickly and dependably over a wide range of ambient temperatures and deliver full rated power.

Gaseous fuel engines have long engine life and reduced maintenance due to more complete combustion and absence of tetraethyl lead resulting in minimum carbon build-up, less sludge formation in the oil, longer valve life and no combustion deposits.

There are several different types of gaseous fuels: natural and manufactured, which are piped in, and the LPG's, propane and butane which are supplied under pressure in tanks. Piped-in gas is the simplest fuel to use since there are no storage problems and the normal supply is quite dependable. The LPG's, on the other hand, present storage problems. LPG is heavier than air and highly combustible, and its storage comes under strict insurance underwriters' regulations.

Gas fuel engines start quickly after long shutdowns because the gas does not deteriorate in storage. To get full rated power similar to a comparable gasoline engine, the gas Btu content must be at least 1,100 Btu per cubic foot.

Diesel fuel engines are inherently heavier and sturdier than comparable gasoline and gas engines, resulting in higher initial costs. Diesel engines have a very long life and maintenance is infrequently required.

Diesel fuel is safe and relatively easy to store for long periods.

c. <u>Cooling System</u>

Engine generators up to 15 kW can be efficiently air-cooled, resulting in lower costs and reduced maintenance. Units larger than 15 kW require a water-cooled engine for maximum cooling protection.

A water-cooled unit may be equipped with a radiator or a city-water system. However, all engines, whether air-cooled or water-cooled, must receive cooling air. Ventilation openings should be located so that cool air can be brought in, forced through the engine cooling system and directly out without circulating around the room. See Figure II-37 for a typical installation in an equipment shelter.

Standby generators should not be installed near sources of unusually high temperatures because inefficient cooling will result. If ambient temperatures fall below 50^{o}F, special accessories such as electric water jacket or manifold heater are needed to ensure dependable automatic starts.

Every standby plant must be equipped with a transfer switch which transfers the electrical load to the standby when commercial power fails and back again when commercial power is restored.

There are two basic types of transfer switches -- manual and automatic. The manual version is a double-throw switch which is operated to transfer the load after the plant is already running. The automatic version starts and stops the generator and transfers the load by relays, not requiring the attention of an operator.

Automatic transfer equipment includes a starter cranking limiter, a trickle battery charger (for the starting battery) and an operation selector switch for testing of the plant. There are many accessories available to meet special needs such as:

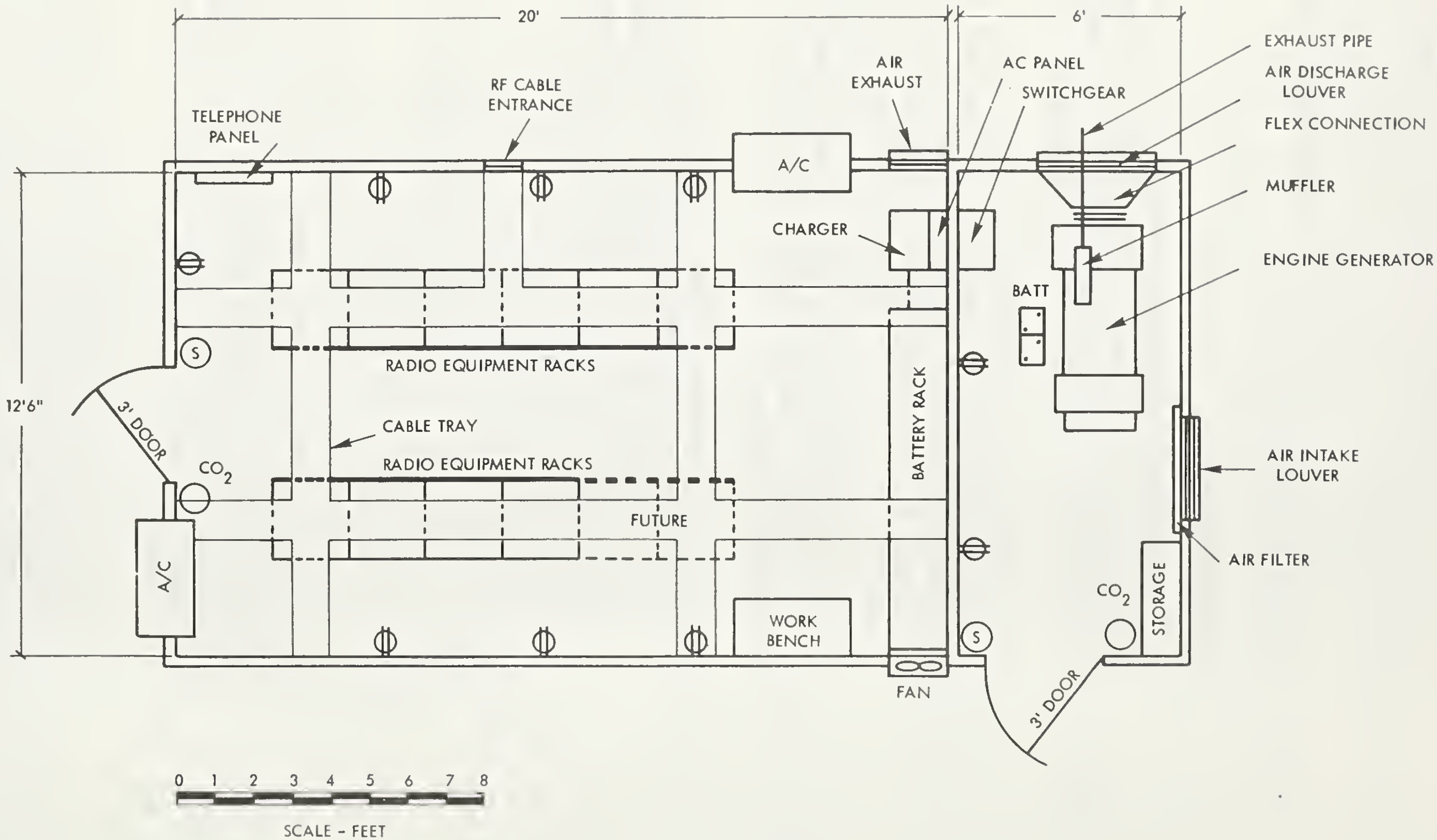


Figure II-37 Typical Equipment Shelter

- Voltage sensitive relays
- Time delay relays
- Clock exerciser
- Safety alarms

A wide variety of meters, controls and safety devices is available. These include:

- Remote start-stop
- Running time meter
- Frequency meter
- Automatic overspeed shutdown
- Low oil pressure shutdown
- Oil and water temperature gauges

Standby generators should be mounted on rubber vibration mounts.

Sites with underground fuel tanks should have a one quart day-tank to provide a ready fuel supply for reliable starting.

b. Vehicular Power Systems

Mobile radio stations installed in vehicles almost universally utilize the automotive 12 VDC negative ground battery as their only power source. Most radio manufacturers offer modification kits for 12 VDC positive ground and for 6 or 24 VDC positive or negative ground.

c. Portable Power Systems

Portable radio equipment typically utilizes a rechargeable nickel-cadmium (Ni-Cad) battery pack which is designed for quick attachment to the transceiver housing. Most radio manufacturers also offer dry cell battery packs.

9. Remote Control Systems

When base stations are not located adjacent to the control point (i.e., dispatch position), some form of remote control system is required to turn power on and off, for keying the transmitter, to change channels or to perform other functions. The control system selected depends upon the distance and type of circuit available between the control point and base station. For distances of 100 feet or less, local hardwire circuits are almost always used. As distances increase, leased telephone circuits or radio links are required for control. There are two principal methods of remote control: DC and Tone. Each is discussed below.

a. DC Remote Control Systems

DC remote control systems utilize multiple low current levels (up to 10 or 15 mA), polarity reversal schemes, or dial pulses. A continuous metallic circuit is required to conduct these DC currents. If the circuit length is such that DC resistance exceeds approximately 2000 ohms, the circuit will require a DC repeater. Audio and DC blocking devices are needed to preserve separate AC and DC continuity from the source to the far end of a simple two wire circuit.

The use of DC remote control is declining rapidly because the telephone companies may be unable to supply metallic pairs in all instances. Many telephone companies have converted their trunk circuits from cable to microwave. Thus, even though the local loops are metallic, a portion of the leased circuit may be non-metallic (i.e. radio), negating the use of DC control voltages.

Before planning to use DC remote control through a leased telephone circuit, the mobile radio system engineer should verify its availability and compare the tariff between it and a non-metallic voice grade circuit. If a reasonable and economical radio path exists between the control point and the proposed base station location, it would be advisable to compare the cost of a privately-owned radio control link versus a leased telephone circuit.

If metallic pairs are available, there are three methods of connecting both audio and control circuits from the control point to the base station:

1. Use two lines: one for audio, the other (metallic pair) for control

2. Use one metallic pair for both audio and control and simplex the control voltage from the center tap of the output transformer to earth ground

3. Use one metallic pair for both audio and control and simplex the control voltage from one line to the other by splitting the output transformer with a capacitor

Figure II-38 shows typical methods of utilizing a metallic pair for audio and DC control functions.

b. Tone Remote Control Systems

The most widely used method of providing remote base station control functions via leased telephone circuits consists of audio signaling. Discrete tones or audio frequencies are generated at the dispatch location for transmission to discrete frequency detectors or decoders at the base station location. Each tone (or tone combination) represents a certain function of the base station that is to be remotely controlled. Signaling tones can be transmitted long distances over typical telephone lines without recourse to special repeaters, as they are compatible with all voice grade transmission circuits. As a rule, a 4-wire circuit is recommended for this control application as it represents less complexity overall than a bi-directional 2-wire circuit carrying receiver and transmitter audio signals plus radio control tones over the same wire pair.

Tone signaling control requires certain safety features to guard against false operation by the momentary presence of a control tone such as can occur in speech when the circuit carries both types of signals. Various highly reliable methods for the reduction of false control commands are in use for mobile radio system applications. These include:

- Guard plus function tones
- Sequential single tones
- Dual tone multiple frequency (DTMF).

A relatively new method of control signaling utilizes two tones transmitted one at a time in a coded sequence. This is called frequency shift (FS) digital signaling.

The guard plus function tones control method is a form of two tone signaling. The guard tone is a fixed frequency; the function tone is a unique frequency for each function. Steady presence of the guard tone is necessary before the

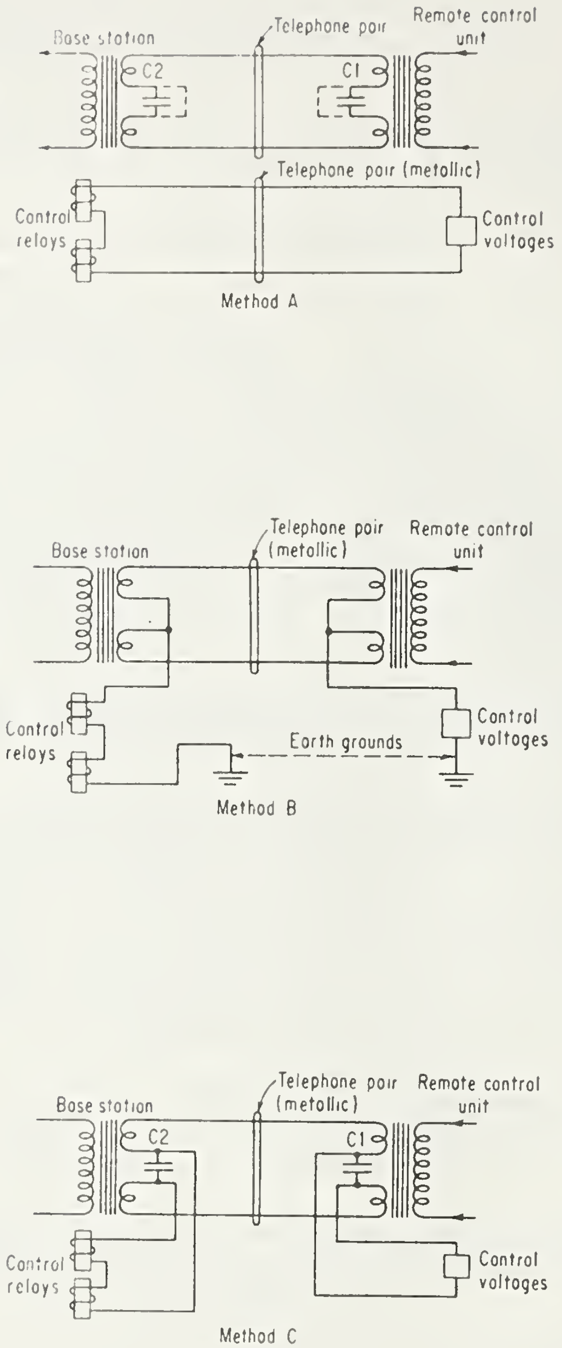


Figure II-38 Typical Methods of Utilizing a Metallic Pair for Audio and Control

control equipment will recognize a function tone. As an additional precaution, the function tone must be present for a prescribed minimum duration before it is accepted as a valid control signal. This time element is usually in excess of the longest possible occurrence of the tone in normal speech patterns. Because this control signaling method is commonly used over telephone circuits where interfering crosstalk of telephone company signaling tones may occur, the control frequencies selected usually exclude any of those used by the common carriers for signaling purposes.

Sequential single-tone control signaling makes use of two, three or more tones transmitted one after the other. Reliability of this mode is predicated upon the probability (or improbability) of these tones occurring in speech in the same sequence and of the same duration (for each tone) as prescribed for the control application. The choice of frequencies to be used for this mode usually excludes telephone company signaling tones for the same reason as explained previously. Normally the amplitude of tone signals used for sequential single-tone signaling is set high enough to materially aid in controlling crosstalk induced false signals.

DTMF signaling, which was developed by the telephone industry, has been adopted by the mobile radio industry as a dependable, economical and flexible method of control. Ten pairs of harmonically unrelated tones are used. These pairs can be taken one per control function, or in combinations to produce large numbers of control signals. Tone generators, detectors and tone pair combination decoding logic are all proven reliable components, as indicated by their common use throughout the telephone industry for the replacement of dial pulse equipment. The tone pairs in use for telephone applications have been standardized as shown below:

Digit	Tone Pairs (Hz)
0	941/1336
1	697/1209
2	697/1336
3	697/1477
4	770/1209
5	770/1336
6	770/1477
7	852/1209
8	852/1336
9	852/1477

The use of two or more tones pairs to represent a control function virtually precludes the possibility of a false

signal from speech patterns. Normally the amplitude used for these signal tones is high, making the detector circuits almost immune to crosstalk problems.

With the advent of the inexpensive microprocessor, FS control signaling (with its great speed and flexibility) is becoming a feasible means of controlling mobile radio equipment. Complex control orders can be transmitted over telephone voice grade circuits in a fraction of the time required by the use of other tone control methods. The FS signal is virtually immune to speech pattern and crosstalk interference. Control functions are identified by digital words which the microprocessor arranges in a programmed order (logic) to perform the desired equipment operation.

Base stations intended for remote control are supplied with a control shelf,and in order to accommodate any of the tone signaling schemes, conversion kits are available for the tone format desired, i.e. guard plus single tone, sequential tone, or DTMF. Additional conversion kits allow control signaling via 2-wire or 4-wire telephone or radio circuits.

At the time of this Bulletin's preparation, the FS digital remote control scheme utilizing microprocessors is beginning to penetrate the mobile radio market. Its first widespread application has been for mobile radio telephone use where high reliability of control signaling is mandatory. Experience to date verifies that this requirement has been met. FS digital control signaling is now being introduced into large scale private mobile radio systems used by the power industry.

FS signaling is compatible with wire or radio transmission control circuits, either 2-wire or 4-wire. Operation is based upon the formation of a specific control word in digital format for each control function. This word can contain instructions or other information of much greater complexity in a much shorter time frame than possible with other tone schemes. Interactive signaling between dispatcher, mobile station and fixed stations is possible within a few milliseconds, assuring positive machine decision concerning radio call completion to the desired party or location. The heart

of the control scheme is the preprogrammed microprocessor which reacts to the digital message to perform a series of known operations making up the control action desired. What parts of the program are involved are determined by the control message word structure. Because of the speed and ability to recognize a large range of command and control words, this remote control signaling scheme can be applied to many more control functions than is possible with any of the other tone or DC control methods.

10. Tone Signaling Systems

The transmission of audio frequency tones over a mobile radio circuit has many important applications. The principal purposes of tone signaling in mobile radio systems are to provide control and to transmit information.

a. Continuous Tone Coded Squelch Systems (CTCSS)

Radio frequencies in the land mobile services are assigned by the FCC on a shared basis. No licensee has exclusive use or rights to any frequency. CTCSS is commonly used when many users are sharing the same radio channel. With CTCSS it is possible to obtain a degree of privacy in communication and to reduce listening to unwanted traffic. CTCSS is commonly called "tone squelch" or "tone coded squelch". The manufacturers call it "Channel Guard", "Private Line" or "Quiet Channel". In a CTCSS mobile radio system each transmitter is usually equipped with a tone encoder and each receiver with a tone decoder. The transmitter tone encoder generates a continuous subaudible tone whenever the push to talk switch is depressed. The decoder-equipped receiver will open the audio circuits to the speaker only if it receives a carrier with the proper tone signal, and will block all other non-coded transmissions on that frequency.

Conventional CTCSS utilizes a continuous single tone having a sine wave waveform. A new version utilizes a digital pulse train having a square wave waveform. The digital coded squelch systems are not continuous; the pulse train is sent out for a short period at the beginning of each transmission. An advantage of digital coded squelch over continuous tone coded squelch is the reduction in false squelch opening due to random spurious tones.

The FCC requires that any mobile relay (repeater) systems be equipped with a continuous coded tone signal to activate the mobile relay transmitter. CTCSS is frequently utilized for this function also.

The use of CTCSS is not limited to mobile relay systems. It is frequently employed in multiple-user shared simplex systems to reduce listening to unwanted traffic. In these systems each group of users is assigned a different low frequency tone.

Continuous tone signaling systems have several advantages:

- The tone information is constant and is parallel with the voice intelligence. Users can begin speech traffic as soon as the PTT switch is depressed.

- The tone is filtered out and is normally not heard in the audio circuits.

- There is no "reset" problem. The control function is present as long as the tone is present and inherently provides a simple "on" and "off" condition. In the event of signal drop outs due to fading or blockage, the communication channel is restored automatically when the signal is again received adequately.

Disadvantages of CTCSS systems include:

- Reduction in the bandwidth available for voice intelligence. Only ± 4 kHz is available instead of ± 5 kHz. This does not occur with digital coded squelch.

- The number of tones (and therefore functions) that can be performed on one channel is limited. Typical commercial CTCSS is available with up to 20 tones. The new digital coded squelch systems provide up to 80 discrete codes.

b. Pulsed Tone Systems

Pulsed tone refers to the transmission of one or more audio frequency tones sequentially or simultaneously over a mobile radio circuit. There are literally hundreds of applications for pulsed tone in mobile radio systems.

The most common application of pulsed tone is for selective calling of individual or groups of mobile stations. In selective calling systems, a tone encoder is installed at the control point console. The encoder usually consists of a 10 or more digit keyboard, each key representing one or more tones. After selection of the appropriate digits, the operator will depress a "send" key which automatically turns on the associated base station transmitter and transmits the tone pulse train. Mobile stations equipped with decoders will open the receiver's audio circuits

when the appropriate sequence of tones is received. Another common application of pulsed tone is in paging systems. These are usually one-way (base-to-portable) transmissions and are repeated to reduce chances of a missed page.

Mobile Telephone Systems (MTS) also utilize pulsed tone for signaling and control. The standard MTS and IMTS schemes utilize frequency shift keyed (FSK) tones.

Pulsed tone is used for a variety of functions in the power industry such as:

- Operation of an audible or visual device
- Remote indication of vehicular equipment status
- Load shedding
- Capacitor and valve control
- Air, noise, and water quality monitoring

The three principal types of pulsed tone systems are:

1. Simultaneous tone
2. Sequential tone
3. Combination of simultaneous and sequential

Each is discussed below.

1. Simultaneous Tone Code Systems

   Simultaneous tone code systems are coded by transmitting two or more tones at the same time in a short pulse.

   The principal advantage of this technique is the ability to transmit a large number of unique codes in a very short time. The main disadvantage is the problem of false operation due to generation of intermodulation spurious tones.

2. Sequential Tone Code Systems

   Sequential tone code systems are coded by transmitting a sequence of tones in a precisely defined time frame. If one tone is lost or does not follow in a given time sequence the entire code must be repeated.

The advantages of this technique are:

- A large number of possible codes
- Difficult false operation

The principal disadvantage is that a longer time is required to transmit a single code because the code is longer than a simultaneous coded tone, and it is usually repeated two or three times due to signal fades.

3. Combined Simultaneous/Sequential Tone Code Systems

Some pulse tone systems have combined simultaneous and sequential coding in order to utilize the advantages of both. The well known Touch Tone R or Dual Tone Multifrequency (DTMF) signaling system developed by the Bell System uses ten logarithmically spaced tone pairs where seven tones are used two at a time. DTMF is now widely used in mobile radio systems in a variety of applications, including interconnection to the public telephone network through automatic patching equipment.

11. Data Equipment

The transmission of voice messages over any communication channel is a relatively inefficient means of exchanging information. In a mobile radio circuit this inefficiency is increased due to the protocols necessary to establish identification and presence between called and calling parties. Voice messages are composed of silence at least 20% of the time due to pauses and silent periods in intelligible speech. Speech itself carries much redundant information. A mobile radio circuit is capable of supporting only a finite number of users who utilize speech for communications exchange. The limit is approached rapidly when verbal exchanges are frequent or lengthy.

To increase the information throughput on a mobile radio circuit, many data transmission devices are available which can replace many of the routine voice exchanges required to establish a transfer of information.

The simplest device is an ID module which transmits a pre-assigned three digit code (using pulsed tones) every time the push to talk switch is depressed in the mobile station. The ID signal is decoded at the control point and displayed to the dispatcher. By adding a "request to talk" (RTT) module and an "acknowledge" (ACK) indicator on the control head of a mobile station, it is possible to initiate and establish a call from mobile to base without the use of voice. The mobile operator merely presses his

RTT switch which momentarily keys the transmitters and sends out the mobile ID and RTT codes. The signals are decoded and displayed at the control point, and if the dispatcher is ready to accept a call, he depresses an ACK key on the console. This signal is transmitted by the base station and decoded and displayed on the mobile control head. When the mobile operator observes the ACK light turn on, he can begin his verbal message. This data "handshake" which takes up less than one second of air time can replace the following typical voice exchange on a busy channel:

Mobile:	"Dispatcher, this is mobile 501"
Dispatcher:	"Repeat please, your call was garbled"
Mobile:	"Dispatcher, this is mobile 501, repeat 501"
Dispatcher:	"Mobile 501, go ahead"

The verbal "handshake" can take 10 or more seconds before any actual transfer of information takes place. This reduces the utilization efficiency of the radio channel and limits the number of users the channel can support. The ID and RTT modules are the basic building blocks of a data transmission system. Many other modules are available for the transmission of routine information. Other frequent voice messages which can be replaced by data transmission include status information such as:

- Available for assignment
- Going out of service
- On assignment - not available

The mobile control head is equipped with labelled momentary action pushbuttons for each desired status or canned message. When depressed, the unit ID and status are automatically transmitted to the base station. At the base station they are decoded and displayed to the dispatcher at his console. The console display can be either status lights (one set of lights for each vehicle) or the ID and status can be displayed on a CRT. CRT displays are normally used with large fleets where status lights would take up too much console space. CRT displays are generally computer-generated.

Some systems include provision for manual or automatic vehicle location (AVL) information. In manual systems, the mobile operator can touch an electronic map which translates X-Y coordinates into coded digital signals, or he can enter a location code into a 10 digit keyboard. The location information is decoded and displayed on an electronic map at the dispatch point or on a CRT.

There are many types of AVL systems available. Most require an external input to the vehicle. These include electronic "signposts" throughout the service area that consist of low power transmitters that continuously broadcast a location code. The vehicle radio receives the location information and stores it in a memory. A polling signal from the base station triggers the vehicle radio which responds with ID, status and the latest location code in its memory. Other AVL systems use triangulation and trilateration methods to derive location information.

Several manufacturers offer a full-keyboard mobile data terminal. These terminals generally provide direct access to a computer data base. The mobile data terminal includes a visual display device such as a CRT, plasma tube or LED display.

12. Computer-Aided Dispatch Systems

Mobile radio systems composed of large fleets of vehicles dedicated to quick response to random calls for service from the public can benefit from a computer aided dispatch (CAD) system. The CAD system is normally associated with a fairly sophisticated data base and a mobile data transmission system which provides ID and status information (as a minimum) automatically. Automatic vehicle location (AVL) is a desirable refinement.

The CAD system provides the dispatcher with real-time information on the status and location of all vehicles in the fleet. The dispatcher's console is equipped with a CRT and keyboard which is used to call up and display fleet status/location information.

Typical CAD systems operate as follows:

> The dispatcher receives a call for service from the public and enters the address into his keyboard. The computer searches its data base for the address and verifies that it is a valid address. Generally the computer can display other information on each valid address such as:
>
> - Nearest cross-street
> - Size and contents of building
> - Account history (for utilities)
> - Special situations (one-way street, road work in progress)
> - Serving substation (electric utility)
> - Nearest manhole (for utilities)

If the dispatcher wishes to dispatch a vehicle to the location, he can instruct the CAD to recommend the closest available vehicle. If a vehicle is within some predefined distance and is available, the CAD will display its ID and location to the dispatcher. If there is no vehicle within the predefined distance or available, the CAD will display the closest unavailable vehicles and let the dispatcher make the selection.

Typical CAD systems include a fleet management information system which provides periodic printouts on vehicle utilization and service efficiency. Since almost every vehicle action is captured by the system virtually any type of management or statistical report can be provided. Figure II-39 is a block diagram of a typical CAD system.

Some manufacturers offer a "package" CAD system which is fairly economical. However, most CAD systems are normally tailored to each customer's requirements and can be quite costly.

13. Technical Characteristics of Mobile Radio Equipment

Power industry mobile radio personnel are frequently visited by sales representatives of manufacturers of mobile radio equipment who provide specification sheets on their equipment.

Unless the power industry individual is an experienced mobile radio engineer, he will be somewhat confused about the meaning of the terms and technical characteristics described in the specification sheets.

The purpose of this section is to assist the inexperienced individual in understanding the contents of the specification sheets. In reading the "spec sheets" it is necessary to realize that many of the specifications reflect FCC Regulations as well as minimum standards and methods of measurement established by the Electronic Industries Association (EIA). The latter include carefully defined conditions and points of reference which are adhered to by all reputable manufacturers. These industry-wide standards permit valid comparisons to be performed on competing brands of radio equipment.

The following are explanations of typical technical characteristics contained in most manufacturer's specification sheets.

a. Transmitters

1. Power Output. This is the rated RF power output at the transmitter's antenna terminal. It is important to know if the transmitter is rated for "continuous" or "intermittent" duty.

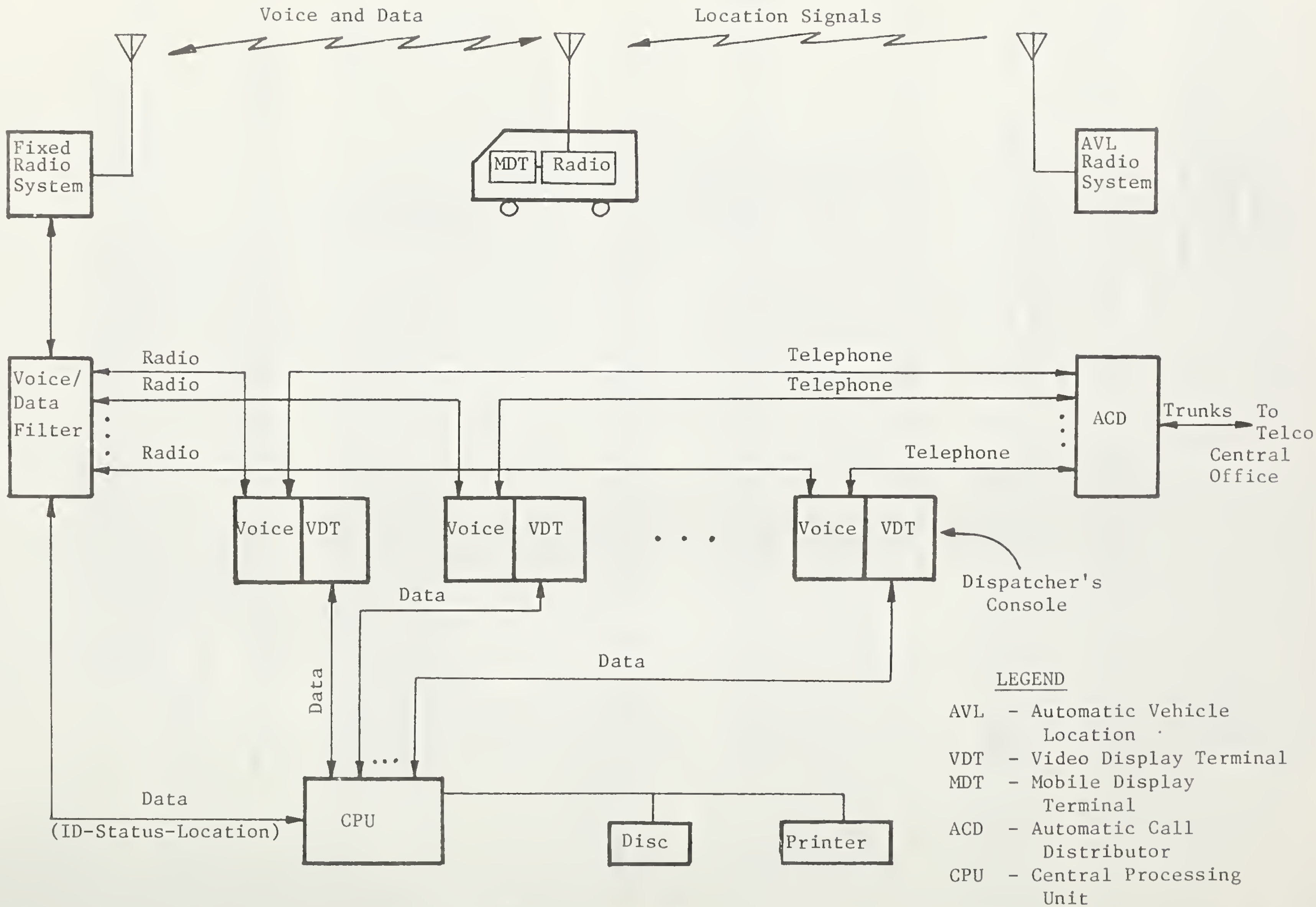


Figure II-39 Block Diagram - Typical Computer-Aided Dispatch System

2. Output Impedance. 50 ohms is the industry standard.

3. Modulation. This is the frequency swing imposed on the carrier by voice. 16F3 is a standard FCC reference for plus or minus 5 kHz deviation. F3 refers to frequency modulated voice. F9 (frequency modulated tones) is also authorized under certain circumstances.

4. Frequency Stability. This is the percent of frequency drift of the output frequency across a specified temperature range. FCC imposes minimum requirements for equipment of different frequency bands and RF power outputs.

5. Spurious and Harmonic Emissions. This is the amount of attenuation provided by the radio transmitter on radio energy falling outside the assigned frequency. It is usually specified as a -dB below the carrier. FCC regulations require that spurious radiation beyond the alternate channel (2.5 times the authorized bandwidth) be attenuated at least 43 plus 10 $\log_{10}$ (power output in watts) dB or -80 dB,whichever is lower.

6. Audio Sensitivity. This is the level of the input signal to the transmitter required for specified modulation.

7. FM Noise. This is the internally generated noise in a transmitter. It is specified as -dB below two-thirds system deviation at 1000 Hz.

8. Audio Response. This is the frequency response of the audio circuits in the transmitter. The pre-emphasis characteristic is usually included in this specification. Typical values are +1, -3dB from a specified pre-emphasis curve from 300 to 3,000 Hz at a 1,000 Hz reference point. The FCC rules require that transmitters having power greater than three watts incorporate a low pass filter for attenuating audio frequencies above 3,000 Hz.

9. Audio Distortion. This is the percentage of distortion added to a voice signal by the transmitter modulation process. Typical values are 3% or less measured at 1,000 Hz at 2/3 system deviation.

b. Receivers

1. Channel Spacing. Most mobile radio systems in the U.S. operate on channel spacings of 15, 20, 25, or 30 kHz in accordance with FCC regulations for the frequency

band utilized. "Splinter" spacings of 7.5 kHz are authorized in the 150-170 MHz band.

2. Modulation Acceptance. This is the IF bandwidth and should be between ± 7 kHz and ± 9 kHz. The wider the bandwidth the less the chance of degraded communication due to netting errors.

3. Selectivity. This is the amount of rejection to undesired adjacent signals provided by the receiver. Specified in -dB.

4. Spurious and Image Rejection. This is the ability of the receiver to reject off-channel signals. The figure stated is the ratio between the sensitivity of the receiver to the desired signal and the sensitivity of the received to any other single off-frequency signal. Specified in dB.

5. Frequency Stability. This is the percent of frequency drift of the receiver oscillator across a specified temperature range.

6. Sensitivity (20 dB Quieting). This defines the minimum signal strength required to quiet the noise at the output of the receiver by 20 dB. Usually specified in microvolts across 50 ohms.

7. Sensitivity (EIA SINAD). This defines the minimum signal strength required to produce at least 50% of the receiver's rated audio power output with a signal + noise + distortion to noise + distortion ratio of 12 dB or better. Usually specified in microvolts across 50 ohms.

8. Noise Squelch Sensitivity. This defines the minimum signal strength required to open the squelch circuit. Usually expressed in microvolts across 50 ohms.

9. Tone-Coded Squelch Sensitivity. This defines the minimum signal strength required to open the tone coded squelch (CTCSS) circuit. Usually expressed in microvolts across 50 ohms.

10. Intermodulation. Refers to the ability of the receiver to suppress undesired mixing of signals from other transmitters. The -dB rating expresses the ratio of the receiver's rejection of these unwanted signals to its acceptance of the desired signals.

11. Audio Output. This is the measurement of the receiver's audio power output (in watts) and distortion (in percent) at the speaker.

12. Audio Response. This is the frequency response of the audio circuits of the receiver. The de-emphasis characteristic is usually included in this specification. Typical values are similar to audio response of transmitter.

Tables comparing FCC or EIA standards with typical manufacturer's specifications for high quality fixed and vehicular and portable radio equipment are shown in Figures II-40 and II-41.

	FCC or EIA Standards*				Typical Manufacturer's Specifications Fixed or Vehicular Radio Equipment			
Frequency Band (MHz)	30-50	150-170	450-512	800	30-50	150-170	450-512	800
Transmitter								
RF Power Output**(watts)	See Figure II-1				330	375	250	125
Frequency Stability (%)	See Figure II-1				$\pm$0.0001% avail.			
Spurious & Harmonics (dB)	$43+10 \log_{10}$ (Power Output)				80-85 dB			
FM Noise (dB)	40 dB				55-65 dB			
Receiver								
Sensitivity 20 dB (µV)	0.4	0.5	1.0	N/A	0.35	0.5	0.5	0.5
Sensitivity EIA SINAD (µV)	0.4	0.5	1.0	N/A	0.25	0.35	0.35	0.35
Selectivity (dB)	70 dB				75-90 dB			
Intermodulation (dB)	60 dB				75-85 dB			
Spurious & Image Reject (dB)	85 dB				100 dB			

* FCC Rules and Regulations, Parts 89 and 91
EIA Standard RS-152-B, Minimum Standards for Land Mobile Communication FM or PM Transmitters, 25-470 MHz
EIA Standard RS-204-A, Minimum Standards for Land Mobile Communication FM or PM Receivers, 25-470 MHz.

** Maximum currently offered (off-the-shelf)

Figure II-40 Comparison Between Standards and Typical Manufacturer's Specifications for Fixed and Vehicular Radio Equipment

	FCC or EIA Standards*				Typical Manufacturer's Specifications for Personal Portable Radio Equipment			
Frequency Band (MHz)	30-50	150-170	450-512	800	30-50	150-170	450-512	800
Transmitter								NOT AVAILABLE
RF Power Output (watts)	Not Specified				0.1 to 6 watts avail.			
Frequency Stability (%)	See Figure II-1				±0.0005%			
Spurious & Harmonics (dB)	$43+10 \log_{10}$ (power output)				50-75 dB			
FM Noise (dB)	40 dB				50-60 dB			
Receiver								
Sensitivity 20 dB (μV)	0.75	0.75	0.75	1.5	0.35	0.5	0.5	
Sensitivity EIA SINAD (μV)	0.5	0.5	0.5	1.0	0.25	0.35	0.35	
Selectivity (dB)	50 dB				55-95 dB			
Intermodulation (dB)	50dB(Portable) 40dB(Personal)				60-75 dB			
Spurious & Image Reject (dB)	50dB(Portable) 35dB(Personal)				50-80 dB			

* FCC Rules and Regulations, Part 89 and 91
EIA Standard RS-316-A, Minimum Standards for Portable/Personal Land Mobile Communications FM or PM Equipment, 25-1,000 MHz.

Figure II-41 Comparison Between Standards and Typical Manufacturer's Specifications for Personal Portable Radio Equipment

14. Antenna Supporting Structures

Supporting structures for mobile radio system antennas include tall buildings, poles and towers. Very often existing AM, FM or TV towers can also be utilized. Each of these structures is discussed below.

a. Tall Buildings

High-rise buildings of ten floors or more can be excellent antenna mounting locations provided that the building is favorably located and high enough to provide coverage for the user's service area. Usually the radio equipment can be installed in a room on one of the top floors, and the transmission line can be kept fairly short, thus reducing line losses.

The antenna can usually be attached to the roof parapet or to the elevator penthouse with relatively simple hardware.

If there are other mobile radio systems antennas installed on a roof top, the prospective user should plan on installing his antennas with as much horizontal separation as possible from the existing antennas to prevent pattern distortion and/or mutual interference.

b. Poles

If the antenna height requirement is 100 feet or less above ground and only one or two antennas need to be installed, a low cost solution is a wooden pole. The pole should be creosoted and equipped with rungs for climbing prior to erection.

c. Towers

If antennas need to be mounted more than 100 feet above ground and no tall buildings are available, it will be necessary to utilize a tower.

Towers are usually of galvanized steel construction and are designed conforming to EIA Standard RS-222B and the AISC Manual of Steel Construction. These documents specify the load application methods, allowable steel working stresses, chemical composition of the steel, tolerances on the materials and structural shape dimensions.

When selecting a tower it is essential to define the following:

1. The number, types, heights, and orientation of antennas that the tower will be required to support both initially and in the future.

2. The need for specialty items such as safety climbing devices, ladders, safety cages, anti-climbing devices, work platforms, rest platforms, FAA painting or lighting, grounding and lightning protection devices.

3. The environmental conditions:

   a. Wind

   b. Ice

   c. Seismic

4. Local building codes and restrictions

5. Soil characteristics:

   a. Allowable bearing capacity

   b. Composition and variation of soil with depth

   c. Water table

   d. Consistency of soil

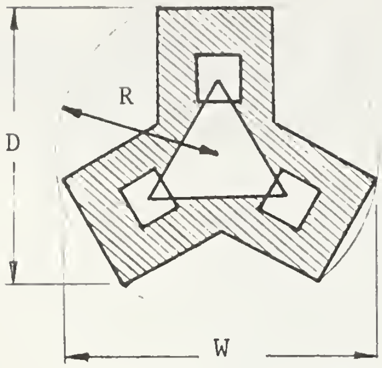
6. Availability of land to install and erect tower

7. Location of nearest airport

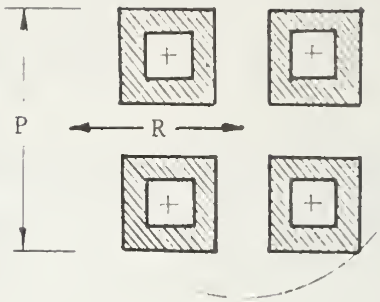
The two generic types of tower are guyed and self-supporting. For very short towers there is not much cost difference, but as heights go up, the cost of the self-supported types increases more or less exponentially, while that of the guyed towers, which have a constant cross-section, increases more or less linearly. So where high towers are required, there are very strong incentives toward the use of guyed towers, provided there is sufficient real estate to install them.

Figures II-42 and II-43 show the required areas for various types of tower. Though these drawings are representative, other types of towers will have different base arrangements and area requirements. An examination of the figures will show the large difference in ground requirements.

3-LEGGED TOWER



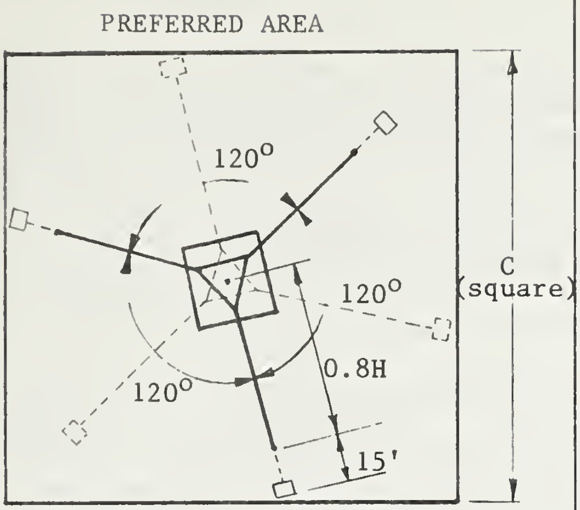
4-LEGGED TOWER

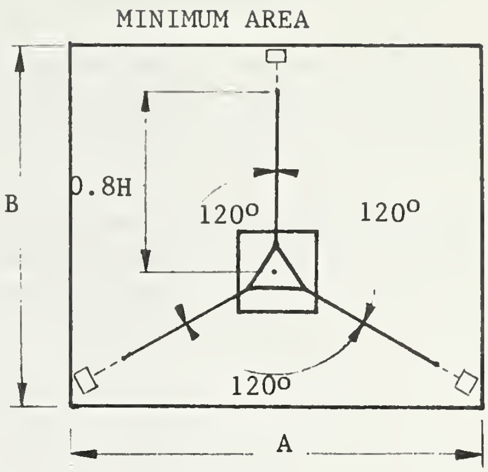


(Shaded portion represents rupture area)

H Tower Height (ft)	R (ft)	W (ft)	D (ft)	Acres	R (ft)	P (ft)	Acres
50	13.8	26.6	23.4	0.01	15.4	21.8	0.01
100	17.3	33.5	29.3	0.02	20.5	28.9	0.02
150	21.9	42.0	37.1	0.04	25.4	35.9	0.03
200	26.4	50.8	44.6	0.05	30.6	43.3	0.04
250	30.5	58.7	51.2	0.07	35.8	50.6	0.06
300	34.8	66.8	59.0	0.09	40.8	57.6	0.08
350	38.0	73.1	64.4	0.11	44.5	64.0	0.09
400	40.0	80.0	68.0	0.12	48.0	68.0	0.11

Figure II-42 Area Required for Self-Supporting Towers





H Tower Height (ft)	C (ft)	Acres	A (ft)	B (ft)	Acres
50	110	0.28	100	90	0.21
100	190	0.83	170	150	0.59
150	270	1.67	240	210	1.16
200	350	2.81	310	270	1.92
250	430	4.24	380	330	2.88
300	510	5.97	450	390	4.03
350	590	8.00	520	450	5.37
400	670	10.31	590	510	6.91

This is the minimum area of land required to permit orienting the tower in any position for antenna path direction.	This is the minimum area of land. However, this area will not always permit orienting the tower in best position for antenna path direction.

Figure II-43 Area Required for Guyed Towers

1. Self-Supporting Towers

Self-supporting towers can be designed to support any desired antenna load, within all environmental conditions, at any desired height. Self-supporting towers are either 3 or 4-legged and are erected in sections (usually in 10-or 20-foot increments) to reach the desired height. The base is designed to withstand the maximum base reactions from the tower leg members. These reactions are compression, uplift, horizontal shear, and overturning moment.

A special case of self-supporting tower is the steel tube or monopole tower. This type of tower consists of a series of 25-foot long tapering steel tubes which fit together. Tower heights of up to 250 feet are possible with these tubes. These towers are not suitable for microwave antennas but are very adequate for mobile radio antennas. Real estate requirements are minimal.

2. Guyed Towers

Guyed towers are similar to self-supporting towers in their capability to mount all types and quantities of antennas. The use of guy wires reduces the size of tower members and foundations, thus significantly reducing overall costs. However, the land area requirements are increased due to the guy wires and their associated anchors. Guys are oriented 120^{o} apart. The distance from the base of the tower to the guy anchor is typically 80 percent of the tower's height plus 15 feet (a 100-foot tower would require 95-foot radius). Guyed towers are of triangular cross-section and are available in increments of 10 or 20 feet.

d. Broadcast Towers

Towers used for AM, TV or FM broadcasting can very easily be used to mount mobile radio system antennas. Many station operators rent antenna space on their towers and floor space for mobile radio base stations. TV/FM towers are usually above 200 feet in height and present less installation problems than AM towers (AM towers are actually antennas and are insulated from ground).

15. Equipment Shelters

Fixed mobile radio equipment to be installed at remote locations requires a shelter or housing that will ensure its protection and continuous operation even under severely adverse weather conditions.

In selecting, specifying or designing equipment shelters, many important factors should be considered including:

- Construction type and building materials
- Interior dimensions
- Exterior dimensions
- Equipment layout
- Environmental control

Each of these factors is discussed below.

a. Construction Type and Building Materials

The choice of the type of construction and of building materials should be largely based, for reasons of economy, on factors determined by location, the availability of required building materials and local skills, local building codes, and zoning regulations. Where site accessibility is poor, the use of lightweight and easily transported shelters may be dictated. Equipment shelters should be fireproof. Some of the building materials to be considered are concrete block, brick, poured concrete, steel, aluminum or fiberglass. If shelters are to be installed in locations of extremely hot or cold temperatures, consideration should be given to materials having the lowest "U" factor (overall heat transfer factor). Insulated fiberglass construction has the lowest "U" factor. Bulletproof construction should be considered for buildings in remote areas or where hunting is permitted.

Buried shelters constructed of large diameter metal tubing have been used sucessfully when extremely high security and stable ambient temperature are essential requirements.

b. Interior Dimensions

Interior dimensions of equipment shelters are dictated principally by:

- The quantity of equipment to be initially installed
- Growth requirements for future equipment
- Required location relationships between equipment groups
- Aisle space requirements
- Maintenance space requirements
- Headroom requirements for equipment and personnel.

The largest mobile radio equipment rack cabinets are approximately 22 inches wide, 21 inches deep and 70 inches high. For planning purposes, a floor space of two feet by two feet is usually assigned for each rack cabinet. Some equipment rack cabinets are only 30 inches high and one usually can be stacked above another to save floor space. It is common practice to install cable trays above the equipment racks. An overall interior headroom of eight feet is usually sufficient to accommodate rack cabinets, cable trays and installation/maintenance space.

Most mobile radio equipment rack cabinets intended for indoor installation have front and rear access doors for maintenance. These doors are usually hinged. A minimum space of 2'6" is desirable both in front and behind racks.

Standard mobile radio rack cabinets can be installed side-by-side since there is no requirement for side access. A row of rack cabinets is called a bay. Shelters having two bays of rack cabinets are normally installed with the front of the racks facing each other. The aisle space between bays is usually a minimum of 3'6" to allow easy movement of test equipment. Reduced aisle spacing is not recommended.

For maximum equipment density and when it is necessary to use the minimum width transportable prefabricated shelters available (8'), it is possible to order fixed mobile radio equipment which mounts in swing-out racks or in pull-out shelves,thus avoiding rear access for maintenance.

Figure II-44 illustrates equipment layout alternatives for various width shelters.

Figure II-45 is a cross-section of a typical equipment shelter illustrating interior vertical space requirements.

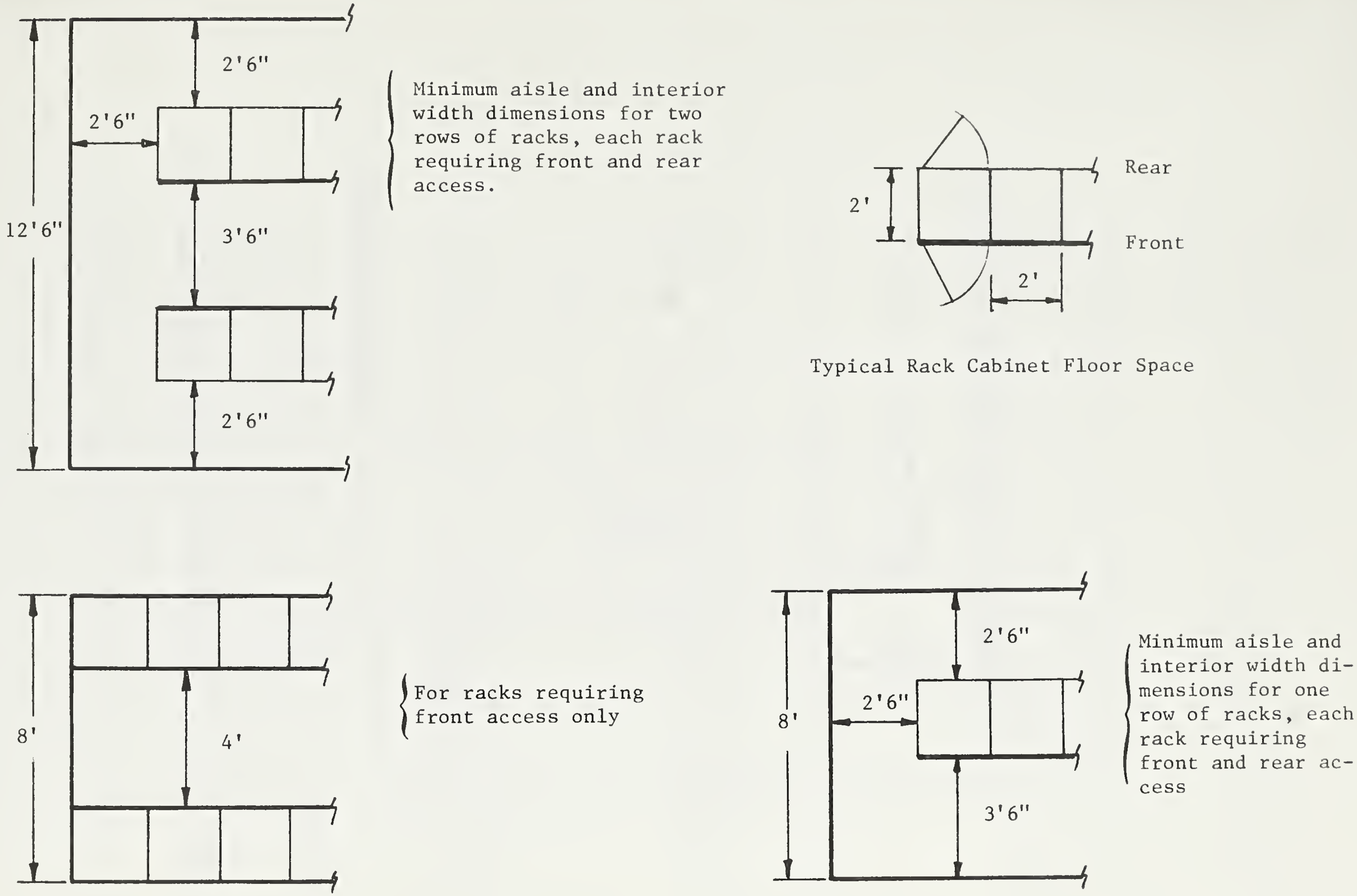


Figure II-44 Planning Equipment Space in Shelters

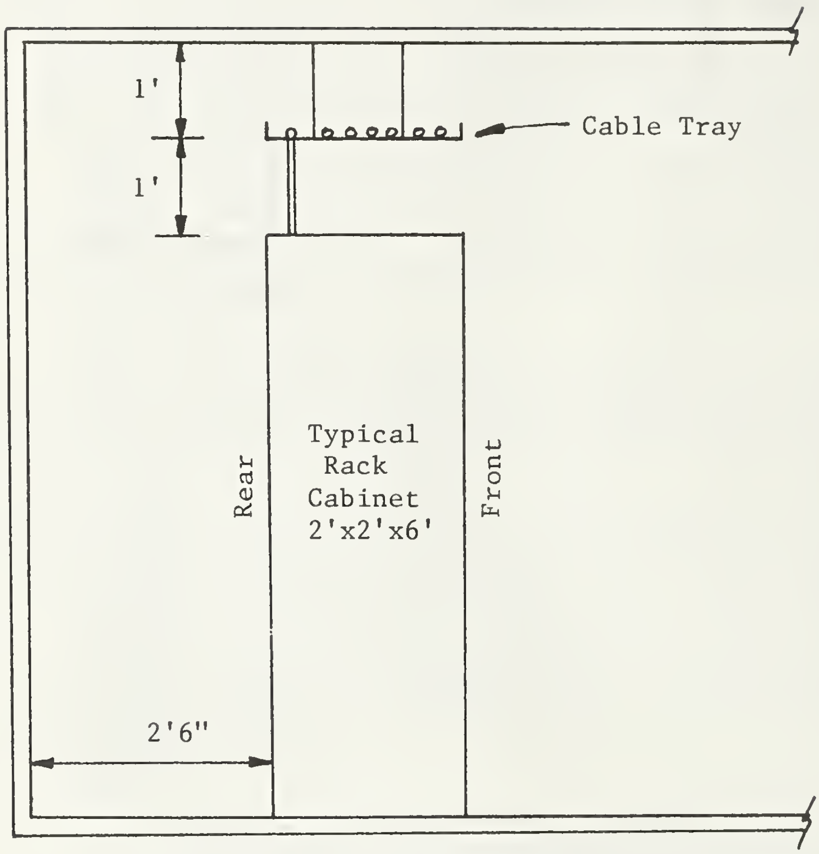


Figure II-45 Cross Section of a Typical Equipment Shelter

c. Exterior Dimensions

For permanent masonry shelters, exterior dimensions can be as required by the user. Generally, a width of 15 feet and a height of 10 feet are commonly used. Length is usually between 20 and 60 feet, depending on equipment quantities.

If transportable prefabricated shelters are required and if these shelters are to be delivered to the site by road transport, it will be necessary to consider intra- and interstate regulations concerning maximum load size permitted on U.S. and state highways. Regulations vary from state to state; however, as a general rule, the maximum dimensions permitted on U.S. highways are:

width	8 feet	(2.4m)
height	13 feet, 6 inches	(4.1m)
length	55 feet	(16.8m)

Special permits and transport procedures are required for objects exceeding these dimensions.

In addition to transportability by road, it may be necessary to consider transportability by cargo aircraft. The most convenient size for air transport are shelters which conform to the military S-280 specification which have exterior dimensions of:

width	7'3"	(2.2m)
height	7'	(2.1m)
length	12'3"	(3.7m)

If shelter widths larger than eight feet are required, it is possible to order two 8-foot wide shelters designed to be bolted together to provide an overall width of 16 feet. The common outside wall for these shelters is removable.

d. Equipment Layout

If the equipment shelter is required to house communications equipment as well as power generators, it is recommended practice for the power generating equipment to be installed in a room dedicated for this equipment and separated by a firewall from the communications equipment room. An exterior door for each room is also recommended.

The equipment in the communications room is usually arranged in one or two rows of racks with appropriate aisle and maintenance space.

The following must be considered when planning the equipment layout in a shelter:

- Place equipment so that cables between equipment are minimum length.
- Equipment should be grouped by category (transmitters, receivers, batteries, etc.).
- Entrance openings for RF feeders, power and telephone cables, and fuel lines should be located for minimum length cable/pipe runs.
- Ventilating fans and air exhausts should be located to provide the most efficient air flow.
- Space for workbench, test equipment, and storage should be conveniently located.

e. Interior Facilities and Systems

The following shelter facilities require consideration:

- Lighting
- Electrical system
- Grounding
- Alarm system
- Fire suppression equipment
- Personnel support

Each of these is discussed below.

1. Lighting

Adequate lighting is essential to facilitate maintenance. A level of 70 foot-candles at 30" above floor level is desirable. Light switches should be installed adjacent to the doors. Exterior lights or floodlamps may be desirable for security reasons or to permit night time maintenance. Extra interior lighting can be provided with overhead coiled reels.

2. Electrical System

Power systems for equipment shelters are discussed in Section II.E.8 of this Bulletin.

Electrical convenience outlets for test equipment should be provided at the base of every other radio equipment rack. In some instances coiled extension cords suspended from the ceiling in self-retracting reels are a practical solution.

3. Grounding

A single-point ground system must be provided for the electrical and electronic equipment installed in the shelter.

4. Alarm System

Each equipment shelter should have alarm sensors for the following conditions:

- Illegal entry
- Commercial power failure
- Standby power system failure or critical condition
- Tower light failure
- Fire or smoke

5. Fire Suppression Equipment

Portable CO_2 fire extinguishers are essential items for each room in an equipment shelter. Automatic built-in Halon gas fire suppression systems are recommended for unattended shelters housing large quantities of equipment or for any shelters housing emergency radio systems.

6. Personnel Support

At attended sites it will be necessary to provide lavatory, kitchen and sleeping facilities. At remote unattended sites where a technician may become snowbound, it is recommended that a store of food and a fold-out bunk be provided.

Figure II-46 is a typical shelter layout designed for unattended operation.

f. Environmental Control Systems

An essential function of an equipment shelter is to provide an adequate environment for the efficient operation

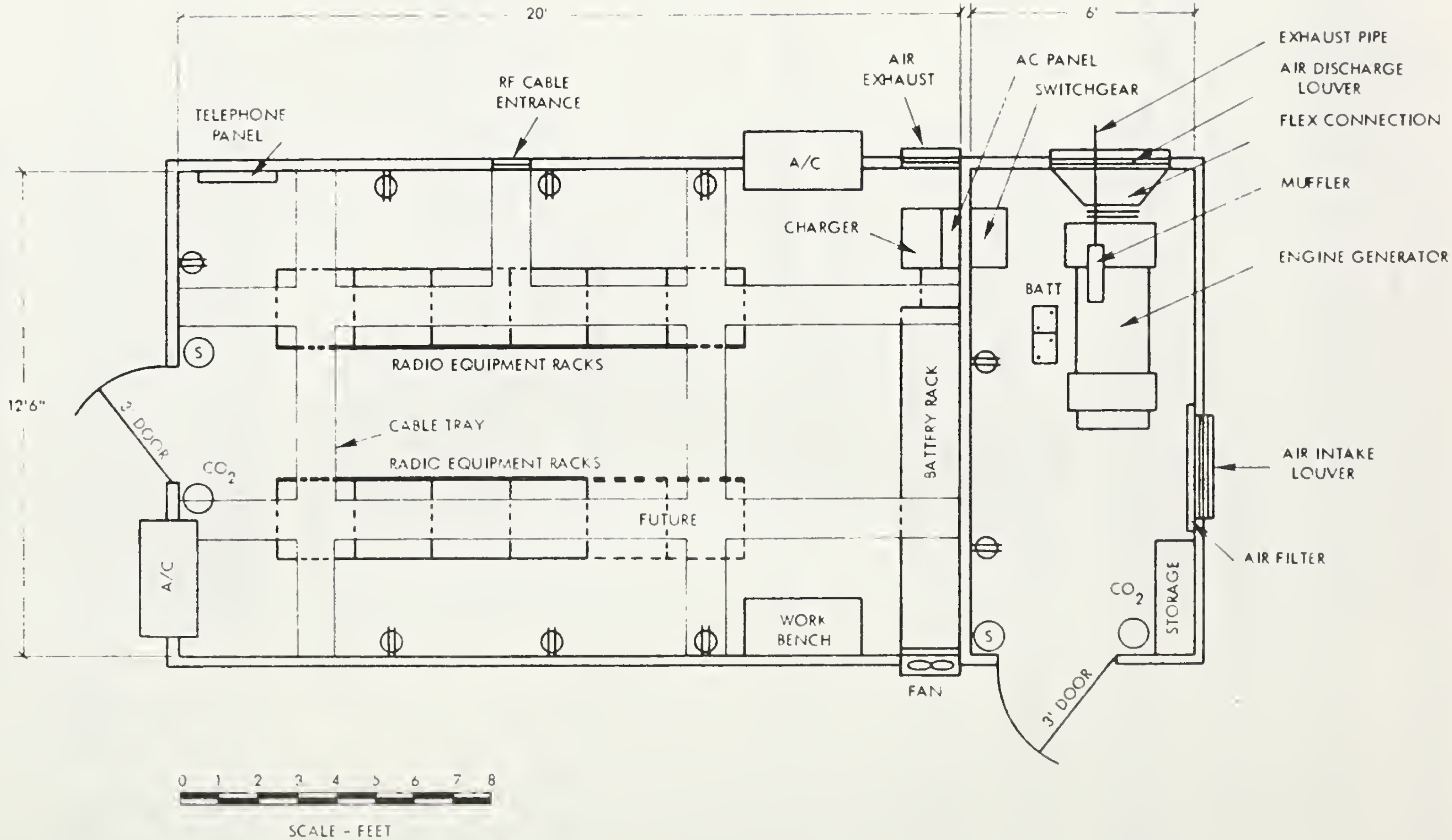


Figure II-46 Typical Equipment Shelter

of equipment and personnel. The shelter must be capable of shielding equipment and personnel against all expected conditions of ambient temperature, humidity, rainfall, snow, ice, wind, dust, sand, corrosive atmospheres and high elevation. Each of these is discussed below.

1. Temperature

Although current mobile radio equipment is capable of operating in extreme temperature ranges*, it is desirable to provide a stable and temperate environment to prolong service life. An interior temperature of 25°C (77°F) is desirable principally for storage battery performance and personnel comfort.

The reserve capacity of storage batteries decreases about 0.5% for each degree decrease in temperature below 25°C. Below -10°C (15°F), crystals form in the battery electrolyte causing rapid decrease in reserve capacity. Above 25°C battery reserve capacity increases but at the expense of service life. Extended periods of operation above 49°C (120°F) may reduce battery life by up to 25%.

The following recommendations should be followed to minimize the amount and cost of shelter heating and cooling systems:

- Use building materials having the lowest possible "U" factor.
- Insulate all exterior surfaces.
- Caulk and gasket around all building penetrations.
- Reduce the use of windows especially on west and southwest exposures.
- Face entrance doors away from prevailing winds.
- Shelter placement, configuration and design should be based on recognized sun shading procedures taking into account longitude, azimuth and sun angles.
- Use roof overhangs or sun screens.
- Paint shelter white or silver to minimize solar heating.

* EIA Standards require equipment to operate from -30°C to +60°C (-22°F to +140°F) and from 0 to 95% relative humidity.

a. Cooling Systems

High ambient temperatures can be controlled through insulation, ventilating fans, thermostatically controlled exhaust fans with automatic louvers, or by air-conditioning systems. Equipment which dissipates a large quantity of heat may be fitted with ducts to carry it directly to the outside or with heat exchangers.

b. Heating Systems

Radiant electric heaters are most commonly used for equipment shelters. Some high power radio equipment has sufficient heat dissipation to provide a portion of the shelter's heating requirements.

Sites equipped with fairly large, continuously running, internal combustion engine generators can usually utilize the waste heat for shelter heating.

c. Ventilating Systems

Ventilation is necessary to prevent buildup of gases during battery charging.

2. Humidity

Extreme humidity conditions may dictate the use of air-conditioning or dehumidifying equipment for equipment protection and operating personnel comfort. In tropical locations, problems of fungus growth may be encountered.

3. Rainfall

In areas of unusually heavy rainfall, precautions must be taken in planning the design of access roads, site drainage, and building design.

4. Snow

Heavy snow accumulation can present problems in site access for operation and maintenance, particularly in remote areas. Special building design may be required to combat rooftop snow accumulation.

5. Ice and Wind

Equipment shelters and towers must be designed for required stability and survival for expected icing and wind conditions. Protection from falling ice is essential for antennas, transmission lines, and personnel. Radomes or other de-icing facilities may be necessary for UHF or SHF antennas or feeds.

6. Dust, Sand and Corrosive Atmospheres

In desert or seacoast areas, protection may be required against airborne dust, sand, and salt. This can be accomplished by the use of simple air filters in all building air intakes. These are usually of the replaceable or washable type, but in extreme cases shelters may require slight pressurization and filters should be of the traveling-screen oil bath type.

7. Storms

Overall station planning must assure continuing operation and survival in the face of expected local storms, including hurricanes, typhoons, etc. Protection against tornado-type winds for towers and equipment shelters is not normally provided.

8. Elevation

Extreme site elevation may pose special problems for operating personnel and electronic equipment design to assure performance objectives and reliability. Engine-driven power generators must be derated for operation at increased elevations.

F. System Design

1. Prediction of Mobile Radio Coverage

a. General

One of the most important tasks in the planning and design of mobile radio systems is the calculation or prediction of coverage, i.e. determining the extent of adequate two-way radio communications between land stations and mobile (vehicular and portable) stations.

The key word in the above paragraph is "adequate". Each user will have to define what he considers "adequate" because the degree of quality in a radio communications

channel is directly proportional to cost. Some users can function with relatively poor circuit quality; others must have perfectly clear and reliable circuits because unambiguous and intelligible exchanges of information are necessary on the first attempt. The latter users include public service and public safety agencies.

The Bell System has established a set of quality criteria for communications channels which lends itself to a convenient definition of adequacy. Figure II-17 summarizes these criteria. For most users (including public service and public safety) the CM 3 circuit is considered as "adequate" and will be the baseline for all further discussions.

A radio circuit between a fixed location and a constantly moving object presents one of the most difficult problems to analyze. At any point in time or at any random location, the moving object will be either in line of sight of the fixed location (best case) or will be totally blocked by hills, buildings, trees, vehicles, or electrically noisy neighbors (worst case). Since randomness is inherent in this type of circuit, the calculation is treated as a problem in probability.

In calculation of radio circuits between two unchanging fixed locations (i.e. point-to-point) the various physical factors affecting the transmission of a radio signal can be carefully analyzed or measured, and a very accurate prediction of the circuit quality can be made. The principal factor which introduces variability into point-to-point radio circuit calculations (changes in the transmission properties of the atmosphere) is fairly well known and can be treated with a high degree of confidence. In the point-to-point radio circuit calculation, the systems engineer can predict performance within $\pm$ 1 dB and with a confidence level of 99.99 percent or better.

As a radio signal radiates from a fixed station to a moving object in a random location, and vice versa, the physical environment provides an infinite number of direct, reflected, refracted and diffracted paths for the radio signal to follow. Buildings and other man-made structures provide a reflecting surface which causes signals to "bounce" and arrive slightly behind directly radiated signals. As these components of the radiated signal arrive at a receiving antenna, some are in phase and the resultant signal will be greater in level than the individual signals, and some are out of phase, and these will cancel out and produce a signal level lower than the individual signals. This mechanism is called "multipath" and is a significant

factor in analyzing mobile radio circuit performance. Typical peaks and nulls will occur approximately every ½ wavelength as a vehicle or portable moves. Figure II-47 illustrates the signal levels experienced in a two-way radio circuit when one of the transmitting or receiving units is in motion. The 20 dB differences in signal level in short periods of time can produce a noticeable reduction in intelligibility, especially in locations at the extreme range of the system. This effect is often called "picket fence" because of the severe chopping up experienced with verbal exchanges.

In mobile radio engineering, because of the great randomness introduced by the motion of the vehicle or portable unit, the systems engineer cannot, and should not attempt to predict performance better than $\pm$ 10 dB and a confidence level of 90%. When mobile or portable units are very close to a base station -- one mile or less -- a confidence level of 99% is defensible.

Another way of looking at "confidence level" is to view a service area as one consisting of N point-to-point circuits between the fixed land station and an instantaneously fixed mobile station. If we take a random sample of 100 locations in the service area, close to the base station there will be a contour that encloses 99 out of 100 mobile unit locations (99%) that can establish adequate two-way communications. Radiating outwards from the base station there will be other contours that enclose 90, 75, 50, 25, etc. locations that can establish adequate two-way communications. Figure II-48 illustrates this concept. Henceforth, the confidence level will be expressed as a percentage of locations in the service area, and it will be called the "Location Variability Factor" (LVF).

Mobile radio users, to a large extent, have standardized their definitions of communications adequacy (or coverage) by stating performance requirements in terms of SIGNAL LEVEL criteria as follows:

- Minimum circuit merit (CM) intelligibility
- Percentage of locations within the service area that can achieve the stated CM -- usually 90%, 75% or 50%.

These definitions are the starting point for calculation of coverage and will be the basis for further discussion.

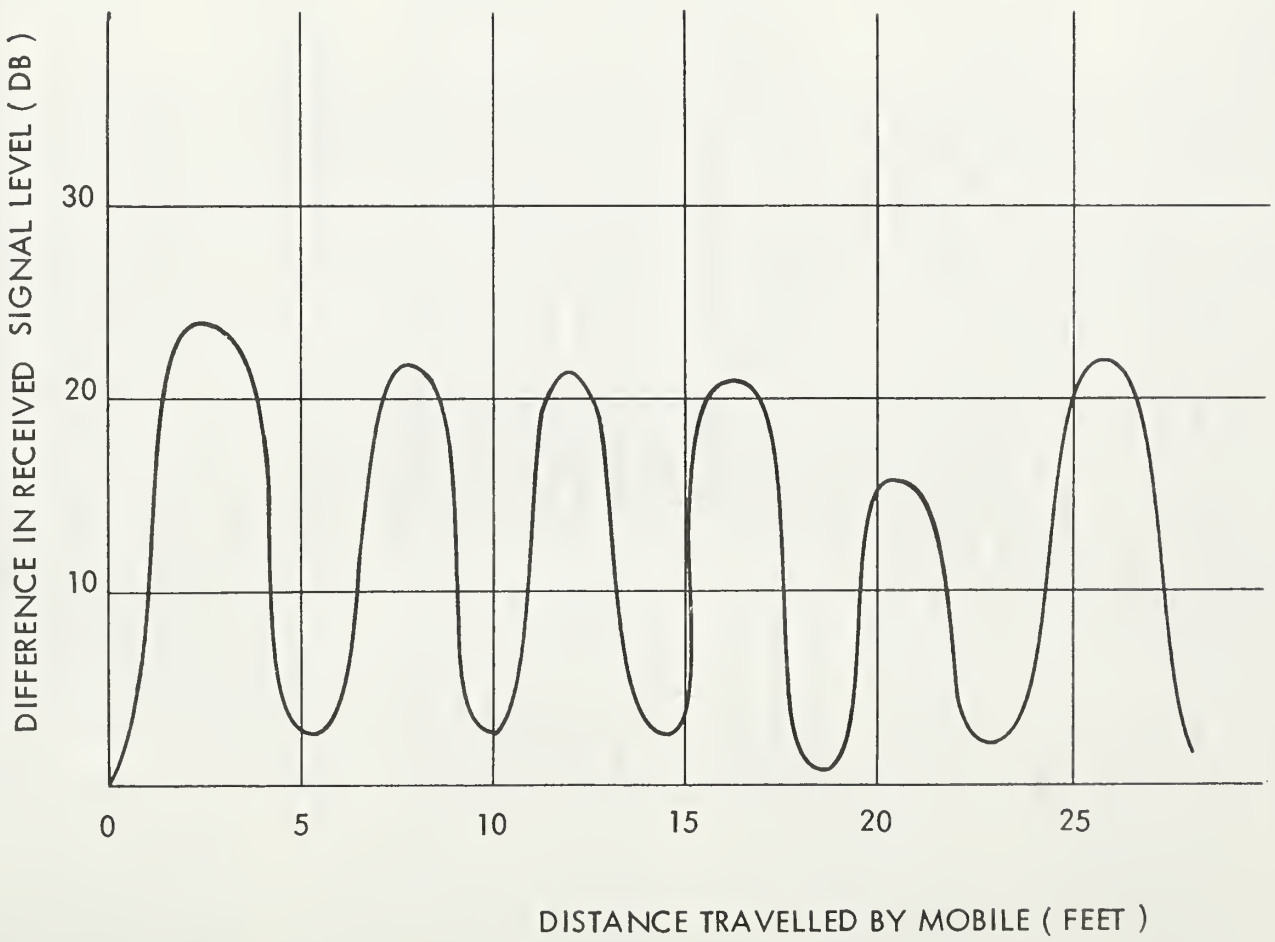


Figure II-47 Two-Way Radio Circuit Signal Waves

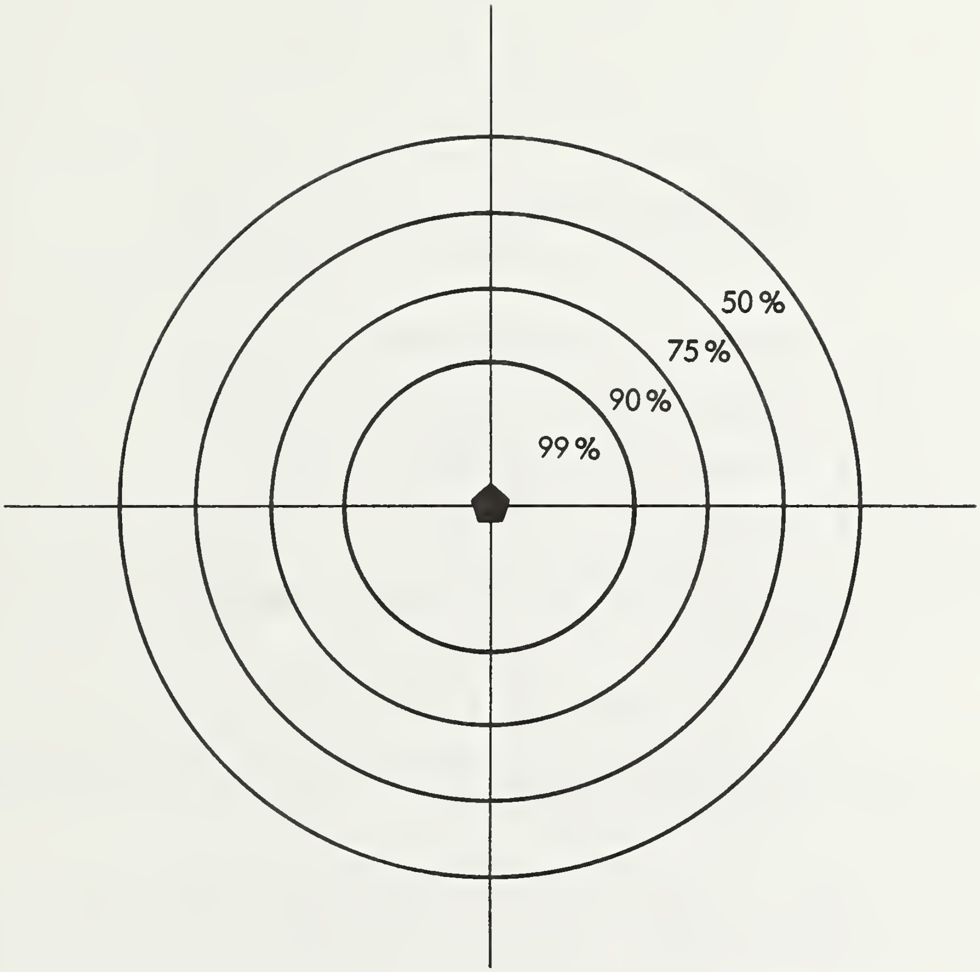


Figure II-48 Confidence Level Contours
Taken Over Smooth Earth

b. Coverage Calculations

Adequate two-way communications between a fixed station and a mobile station are entirely dependent upon the following variable factors:

- Distance from transmitter to receiver
- Antenna height
- Transmitter power
- Antenna gain
- Receiver sensitivity
- Local electrical noise
- Cable and connector losses
- Signal processing equipment losses
- Shadow losses (buildings, hills)
- Foliage losses

In addition the following "adequacy" factors must also be considered:

- Circuit merit (CM) - usually CM-3
- Percentage of locations in service area that require adequate communications (e.g. 50, 75 or 90%) or LVF (nominally 50%)

The principal factor affecting land mobile radio circuits that determines adequacy of two-way communications is antenna height. A very high base station will have line-of-sight with most of its mobile stations. A useful formula for determining the line-of-sight coverage is:

$$D = \sqrt{2h_1} + \sqrt{2h_2} \text{ miles} \qquad [1]$$

where

D = range in miles

h_1 = height of base station antenna (in feet) above ground

h_2 = height of mobile station antenna (in feet) above ground

Since the mobile antenna is normally at 6 feet above ground, formula [1] can be rewritten as

$$D = \sqrt{2h_1} \quad = \quad 3.5 \text{ miles} \qquad [2]$$

A base station antenna 100 feet above ground level would therefore have a line-of-sight range to mobile stations of:

$$D = \sqrt{2 \times 100} + 3.5$$

$$= 14.14 + 3.5$$

$$= 17.64 \text{ miles}$$

This approach will normally yield usable "first cut" estimates of coverage assuming no terrain or building obstruction losses, no electrical noise, CM 3 circuit adequacy, and 50% LVF.

Detailed radio coverage predictions beyond this "first cut" approach are always necessary in order to arrive at a conservative and reliable estimate for each user. Urban and rural users will have different factors to consider, each frequency band has unique characteristics, and service areas which include many hills or dense foliage will each present special cases, each of which must be analyzed independently. The approach presented below will provide guidance for the majority of users in refining initial coverage prediction estimates.

c. Detailed Coverage Predictions

Once the initial coverage estimates are completed, it is necessary to prepare detailed coverage predictions. In many instances these coverage predictions are required as part of the supplemental information submitted to the FCC when applying for new frequencies. It is good practice to document the expected coverage in the event radio interference becomes a problem, or if the service area is changed in the future.

Figures II-49 and II-50 are forms which can be utilized to compute all types of mobile and portable radio system predictions. These forms have been designed both for base-mobile and base-portable computations.

1. Net System Gain Computation (Figure II-49)

Net System Gain is the algebraic sum of all the system gains and losses that affect a particular radio circuit. A fixed radio unit would be able to communicate

Frequency ________ MHz
CM 3 Signal Level _______ dB*

Azimuth _____

	Units	TALK-OUT				TALK-BACK				See Figure
		Urban		Suburban		Urban		Suburban		
		90%	68%	90%	68%	90%	68%	90%	68%	
SYSTEM GAINS										
1. Transmitter Power	dBw									II-51
2. Antenna Gain - Base	dBd									Spec sheets
3. Antenna Gain - Mobile	dBq									Spec sheets
4. Receiver Sensitivity - Effective	dBw									II-52
5. Total Gains	dB									
SYSTEM LOSSES										
6. Transmission Line	dB					1	1	1	1	II-31
7. Connectors	dB	1	1	1	1	0	0	0	0	
8. Transmitter Combiner - Base	dB									Spec sheets
9. Receiver Multicoupler - Base	dB									Spec sheets
10. Mobile Duplexer	dB									Spec sheets
11. Building Loss	dB									II-53
12. Foliage Loss	dB									II-16
13. Shadow Loss	dB									II-15
14. Portable Differential	dB									II-54
15. Margin	dB									II-55
16. Total Losses	dB									
NET SYSTEM GAIN	dBw									

*See Figure II-18

Figure II-49 Net System Gain Computation

Base Antenna Height		Talk-Out					Talk-Back			
			Urban		Suburban		Urban		Suburban	
		Units	90%	68%	90%	68%	90%	68%	90%	68%
100'	Net System Gain	dBw								
	Range	miles								

Figure II-50 Coverage Computation

adequately with any of its associated mobiles as long as the signal level received by the receiver is within the Net System Gain. This Net System Gain also defines a Maximum Path Attenuation (MPA) contour that assumes a specific CM circuit quality (CM-3 in this case) and LVF.

Figure II-50 is designed to accommodate the most commonly found coverage calculation situations. Other special coverage calculation cases can also be accommodated with this form simply by changing column headings.

The discussion below explains how to enter values for each line in Figure II-49.

Frequency (MHz). Enter the center frequency in MHz if the system will use two or more frequencies. Not a critical item.

Azimuth. If the service area includes rugged terrain, dense vegetation, or heavily built-up urban areas, it is wise to calculate Net System Gain for radials which go through these difficult areas.

CM 3 Signal Level. Refer to Figure II-18.

For most mobile radio coverage calculations, it is necessary to compute both the talk-out (base-to-mobile) and the talk-back (mobile-to-base) Net System Gains. The two cases are rarely the same because of the difference between base and mobile transmitter power output. Also, the signal processing equipment associated with the base station transmitter can sometimes introduce losses up to 6 or 8 dB. Losses of this magnitude are hardly ever encountered with base station receiver signal processing equipment. In some instances, base stations operate with two antennas, one for transmit and one for receive -- these are generally at different elevations above ground or may have different gain ratings.

Line 1. Transmitter Power

Convert the transmitter's rated RF power output from watts to dB above 1 watt (dBw) using the formula

$$\text{dBw} = 10 \log_{10} \frac{P_1}{1}$$

where P_1 = Power in watts

Figure II-51 provides a quick method of solving the same problem.

Line 2. Antenna Gain - Base

Use the rating (in dBd) provided by the manufacturer on the specification sheet of the antenna selected for base station use. If the antenna is directional obtain the dBd rating for the azimuth of interest from the manufacturer's horizontal radiation pattern (usually found on the specification sheet).

Line 3. Antenna Gain - Mobile

Use the rating (in dBq) provided by the manufacturer.

Line 4. Receiver Sensitivity - Effective

See Figure II-52.

Line 5. Total Gains

Add lines 1 through 4.

Line 6. Transmission Line

For the Talk-Out case use Figure II-31 or the manufacturer's attenuation curves.

For the Talk-Back case this line is 1 dB.

Line 7. Connectors

For the Talk-Out case this line is 1 dB. For the Talk-Back case this item can be ignored (0 dB).

Line 8. Transmitter Combiner - Base

Use only for the Talk-Out case if base station transmitter combiners are included in the system. Refer to manufacturer's specification sheets for insertion loss. Be sure to include losses introduced by filters, cavities or any other transmitter signal processing equipment.

Line 9. Receiver Multicoupler - Base

Use only for the Talk-Back case if base station receivers are connected to a multicoupler. Usually these devices have amplifiers to make up for the splitting losses and have a net insertion loss of 0 dB. Be sure

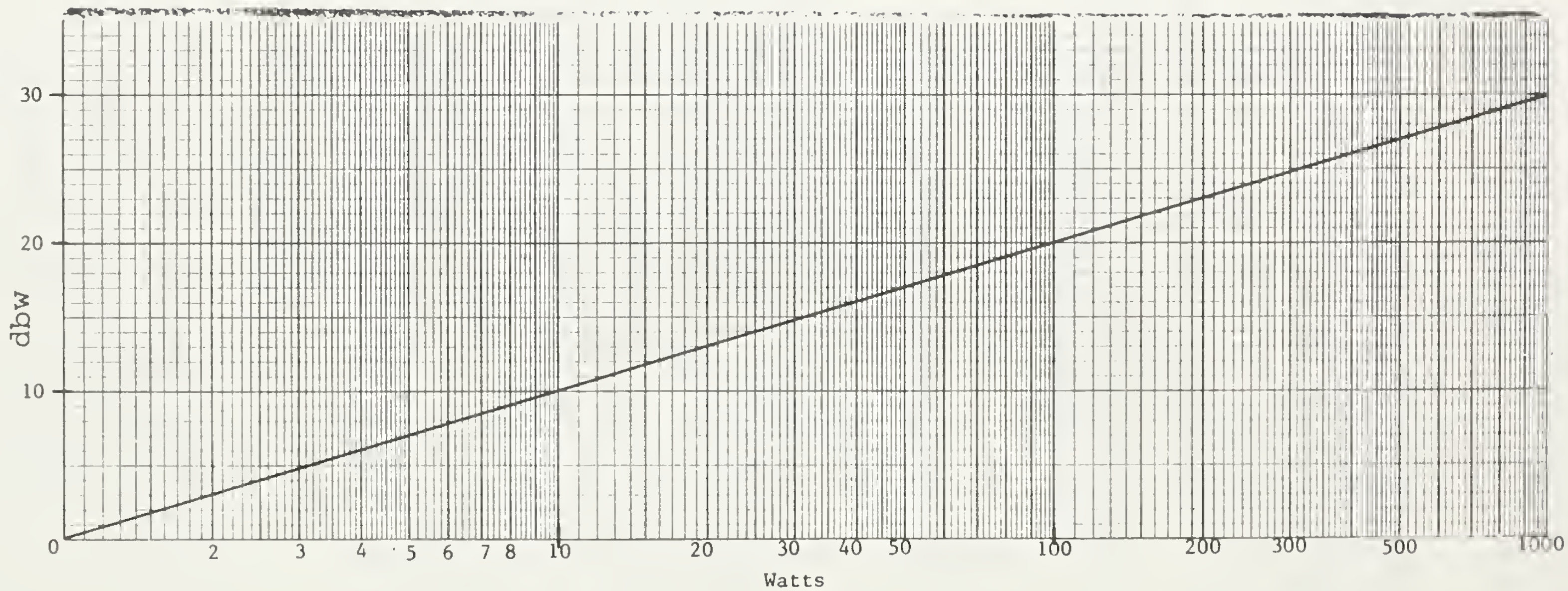


Figure II-51 DBW vs. Power in Watts

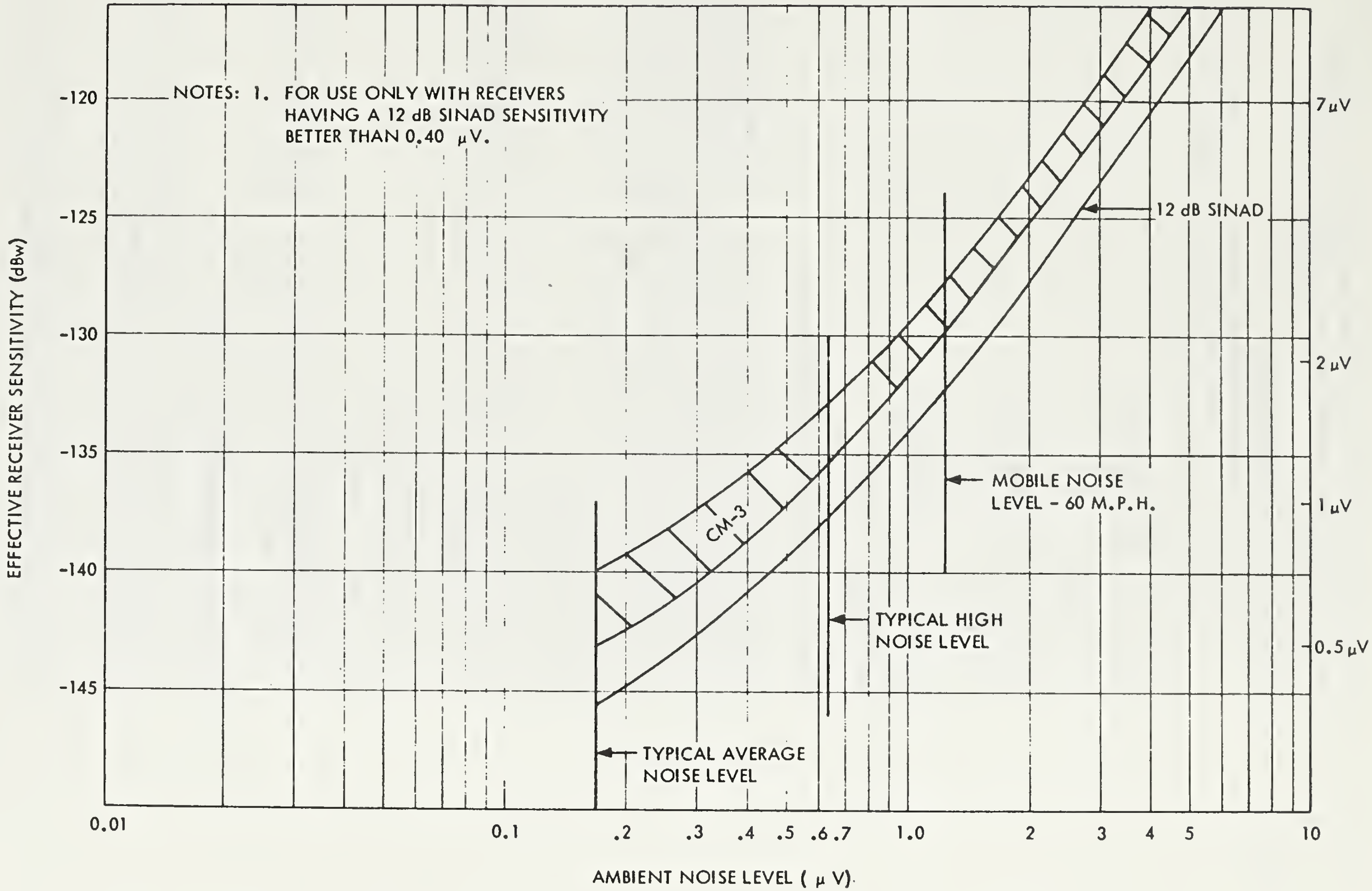


Figure II-52 Effective Receiver Sensitivity

to include losses introduced by filters, cavities or any other receiver signal processing equipment.

Line 10. Mobile Duplexer

If the mobile units are equipped with duplexers, include the manufacturer's insertion loss.

Line 11. Building Loss

See Figure II-53.

Line 12. Foliage Loss

See Figure II-16B.

Line 13. Shadow Loss

See Figure II-16A.

Line 14. Portable Differential

In calculating net system gain for a portable radio system, due allowance must be given to the inefficiency of the portable antenna with respect to a mobile antenna. The path loss curves (Figure II-56) are based on an efficient mobile antenna at a height of 6 feet above ground. Use the loss factors shown in Figure II-54.

Line 15. Margin

For the different location variability factors (LVF) desired, use Figure II-55. Note that for 50% LVF coverage the margin is 0 dB.

Line 16. Total Losses

Add lines 6 through 15.

Now NET SYSTEM GAIN is obtained by subtracting total losses (line 16) from total gains (line 5).

2. Coverage Computation (Figure II-50)

Using the Net System Gain figure obtained with the use of Figure II-49, the system engineer can now calculate the probable range (in miles) of the system.

Figure II-56 shows path loss curves which relate the net system gain, base station antenna height, and range.

Figure II-56 allows the system engineer to select the optimum base station antenna height for a specific range, or he can calculate range from a given base station antenna height. Use Figure II-57 to estimate the <u>effective</u> antenna height.

Frequency Band(MHz)	Building Description	Typical Loss(dB)
30-50	Office & High Rise	10
	Shopping Centers	3
	Frame Buildings	0
150-174	Office & High Rise	30
	Shopping Centers	20
	Frame Buildings	3
450-512	Office & High Rise	24
	Shopping Centers	20
	Frame Buildings	3

Figure II-53 Building Loss

Frequency Band(MHz)	Antenna Configuration	Average Differential(dB)
150-174	Telescoping Extended	3
	Helical	8
450-470	Telescoping Extended	10
	1/4 λ Spring	9
	Helical	14

Figure II-54 Loss Factors Portable Radio Differential

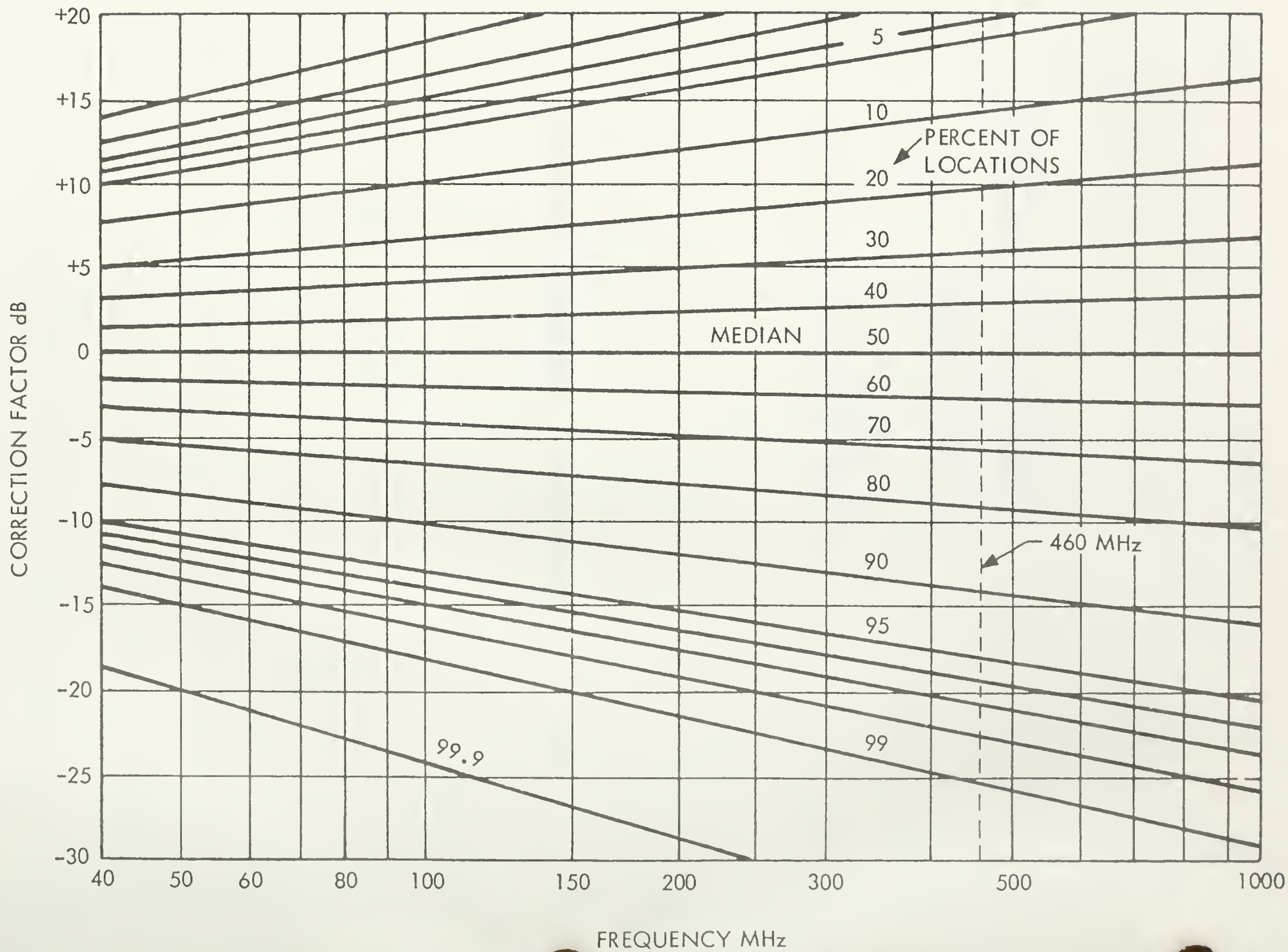


Figure II-55 Lc .on Variability Factor (Margin)

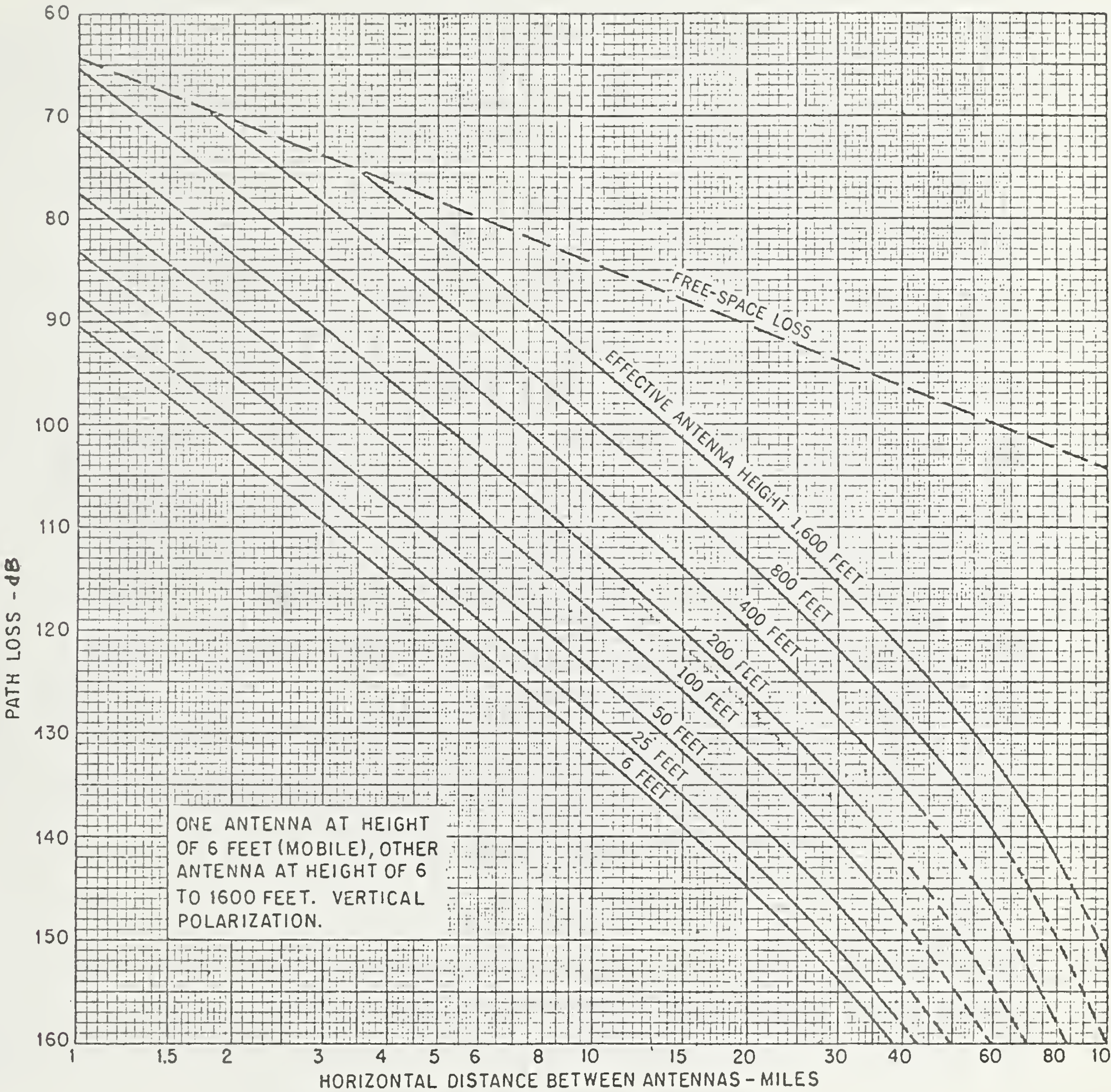


Figure II-56(a) Path Loss at 40 MHz

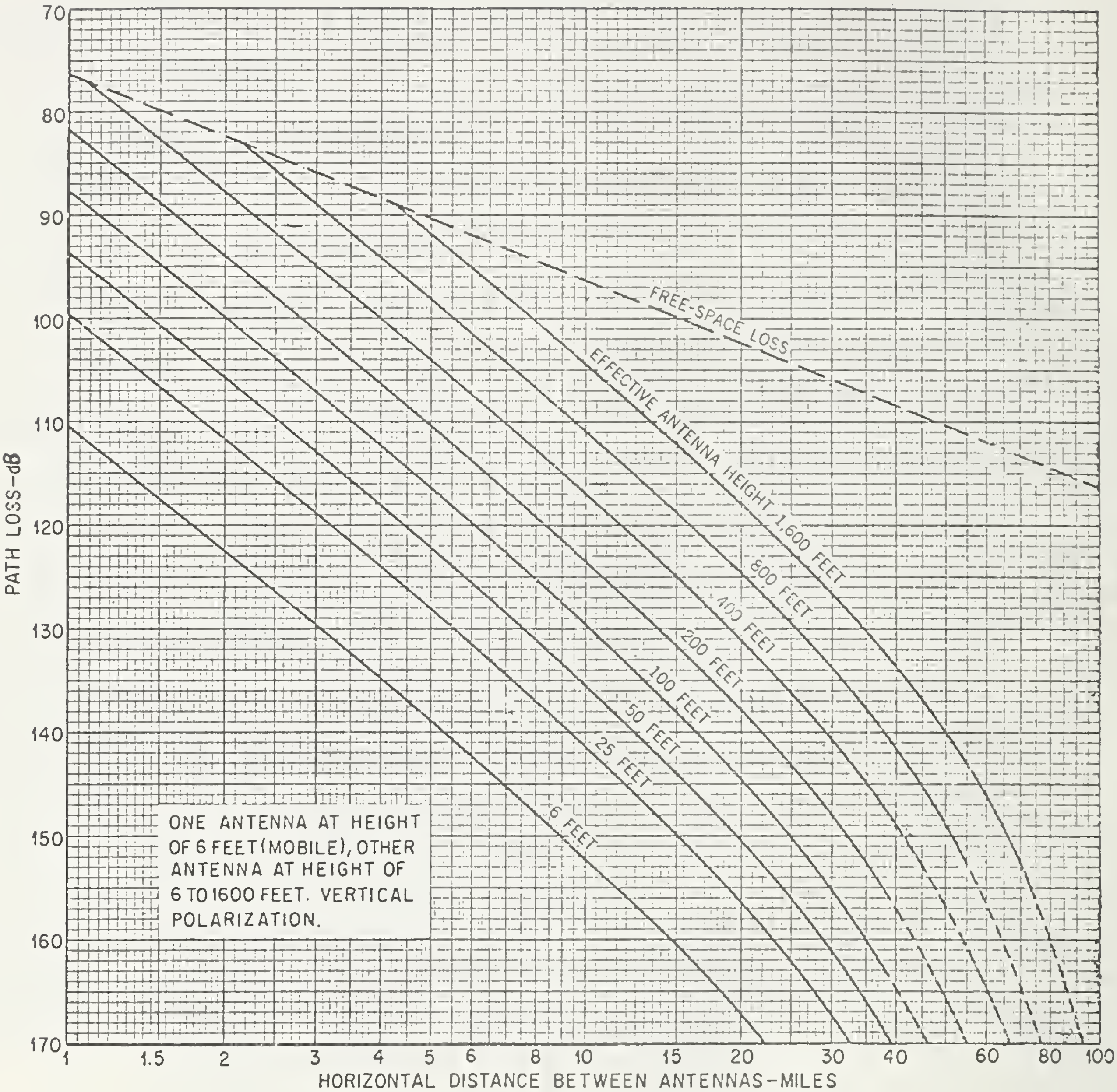


Figure II-56(b) Path Loss at 160 MHz

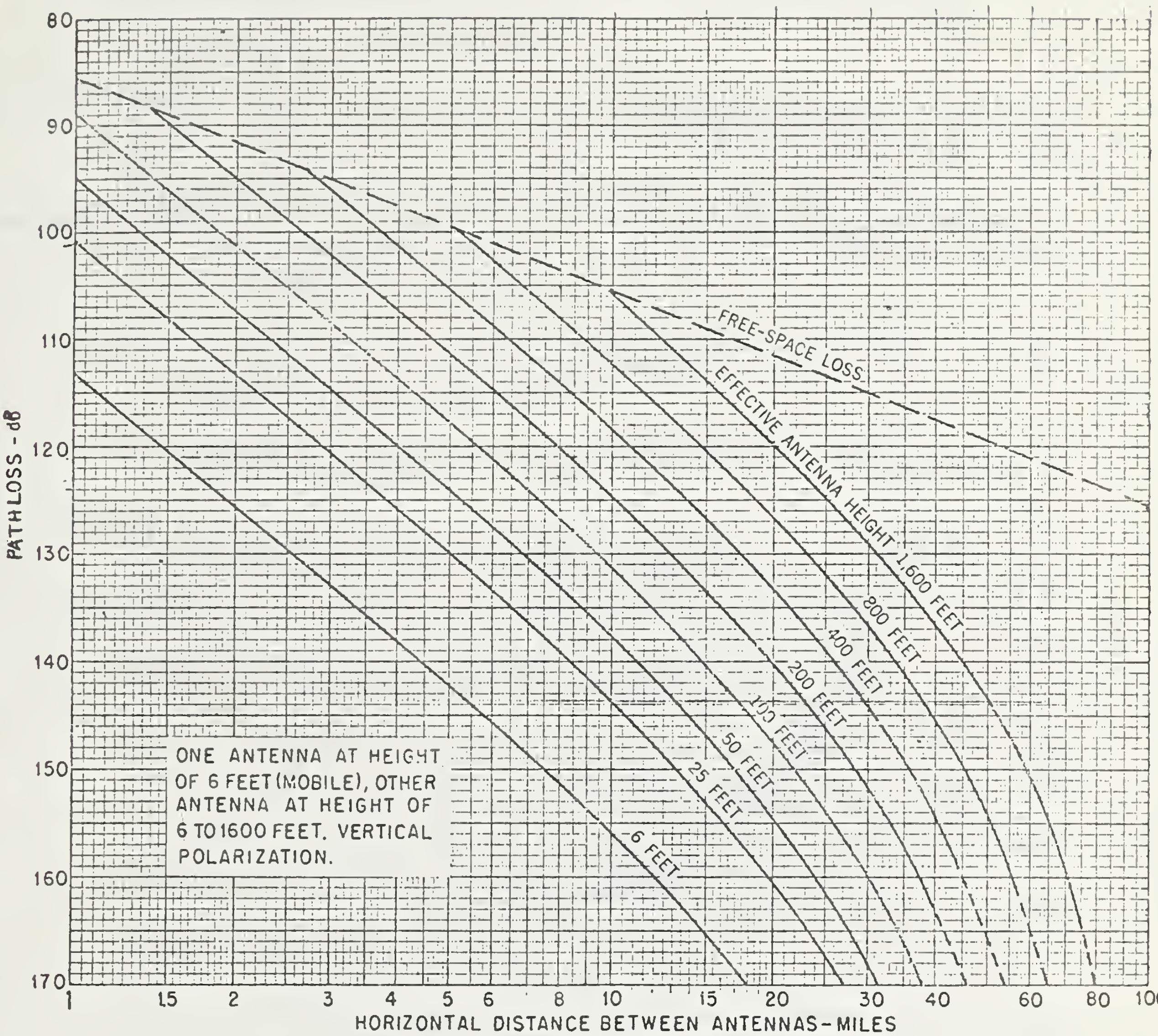


Figure II-56(c) Path Loss at 460 MHz

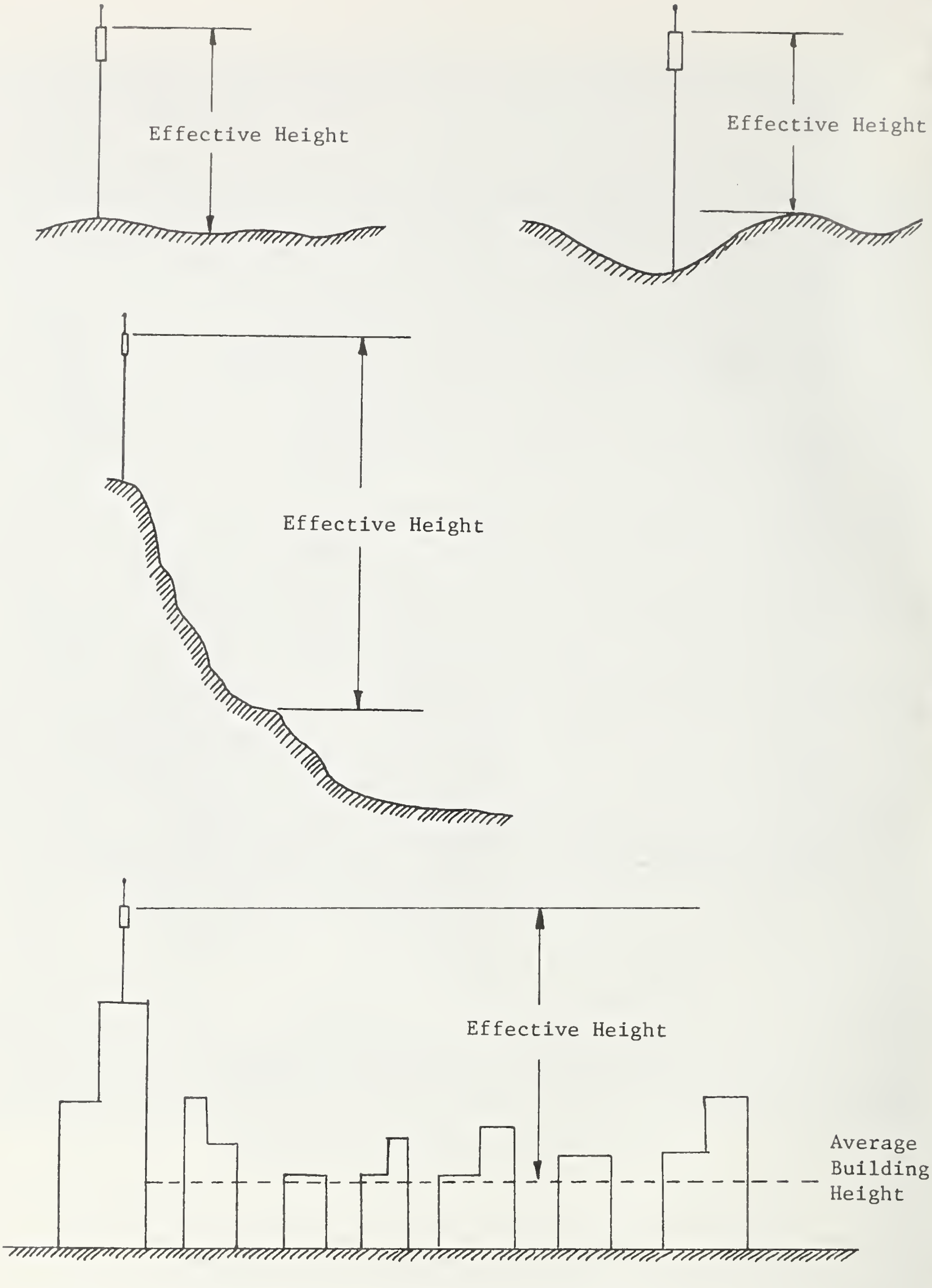


Figure II-57   Effective Antenna Height

III. OPERATIONS AND MAINTENANCE (O&M)

A. Introduction to O&M Philosophy

Mobile radio systems require planned and systematic attention to changes in the Borrower's operating needs and equipment performance on a continuing basis throughout its projected life cycle. Three fundamental reasons for instituting a viable O&M program are:

- System configurations must adapt to meet changes in the Borrower's business activities.
- Equipment modernization providing improved service must follow the state-of-the-art without penalizing the service life of existing system components.
- Equipment failures and system downtime must be kept to an absolute minimum.

The primary advantage of mobile radio communications is the flexibility provided the user. Communications can be established between locations that cannot be served (physically and economically) by fixed plant systems such as wireline telephone. In order to achieve this, the mobile radio system is comprised of fixed radio facilities which serve the vehicular radios assigned to it. How these vehicular radios range about or away from a fixed facility, and how many are to be served by it, is the ever changing subject of operations (and attendant requirement of modifications). In the power industry, the ever expanding need for energy service is reflected by the growth of its mobile radio systems. Fixed facilities require upgrading to handle increasing traffic loads; and new facilities are required as communications are extended geographically. Inasmuch as system growth is a continuing function, it will span generations of equipment evolution. Introduction of new equipment designs and capability represents modernization that requires technology management in order to protect existing equipment from forced obsolescence. Equipment that is economically viable over a practical life cycle is prone to failure. Experience with electronic components has provided the base upon which the mean time between failures (MTBF) can be predicted, and system failures can be reduced through good maintenance practices and policies. Judicious utilization of all of the above propositions is required to establish the O&M philosophy and plan applicable to each mobile radio system.

1. Development of the O&M Program

There are a number of primary considerations that need to be taken into account when developing an overall O&M plan. A number of these factors should be given full attention during

the initial conceptual design phases of the Mobile Radio System.

a. Traffic Criticality

How critical is the traffic being carried over the communications system? Is it routine, emergency, or pertaining to the safety of human life? Mobile radio systems are considered a very reliable form of radio communications. They do fail however, for no practical system is designed to operate with 100% availability. There is always calculated risk of failure. Proper O&M programs ensure and/or improve the risk factor by providing proper system surveillance and quick repair in the event of failure.

b. System Availability

In defining the availability of a mobile radio system, consideration must be accorded propagation, equipment faults, and the mean time to repair (MTTR) a failure. Statistically each of these factors can be characterized in the design phase and should be engineered to meet the required system availability as defined by the system operational objectives. Once the system is designed and equipment selected, it is possible to calculate allowable MTTR and thus develop an O&M strategy for the system. MTTR is composed of the following elements:

- Time to reach the site
- Time to locate the trouble
- Time to isolate the fault
- Time to effect repair
- Time to restore the system to working order

For mobile radio systems the site access time is a matter of time to alert O&M personnel and travel time to the site. For a power transmission right-of-way system (involving distances that render the "time to reach the site" excessive), minor maintenance facilities and personnel are sometimes distributed along the system to assure early restoration of service.

It is common to have one such facility every 3-5 radio stations. When making the selection, estimates are made of travel time to each site from the proposed minor facilities. As a practical matter, these times should be limited to no more than 3 hours. The minor facilities may be staffed

during the day time. As a minimum, there should be someone on call 24 hours per day.

c. Mobile Radio Availability

Mobile stations are normally assigned an MTBF by the manufacturer. As a rule this time will be greatly exceeded by the equipment, but can be materially shortened by the vehicular installation. Likewise, rough handling of hand-carried units can drastically shorten their predicted MTBF.

As discussed elsewhere in this Bulletin, a mobile station fault is not considered as a system failure, and is not included in the system MTTR design objective.

In order to assure installed MTBF rates equal to manufacturer's rates, an agressive preventive maintenance policy is required. A considerable percentage of vehicular radio failures can be traced to mechanical malfunctions such as improper and loose cable installation, chafed insulation, broken wires, moisture in the antenna base, loose mountings, and similar physical problems that lend themselves to correction before failure sets in. These can be readily found and the malfunction prevented by applying comprehensive inspection techniques on a periodic maintenance basis for the vehicular installation.

Another factor affecting mobile radio availability is the ability to replace a defective unit with an operational one in a few minutes. For an extended right-of-way mobile radio system, this represents the location of spare units at minor maintenance facilities. The number of applicable spares can usually be set at a 1 to 25 ratio, with no fewer than two for a fleet of 25 or fewer vehicles to be serviced from such a facility.

Each Borrower should monitor the mobile radio unit service rate and adjust the quantity of spares to meet his specific maintenance conditions. The objective should not be to have a serviceable radio available for each mobile unit failure. If it is necessary to transport a unit to a central radio repair facility, such as can be the case for an extended right-of-way mobile radio system, then the repair delay caused by travel from and return to a minor maintenance facility may require additional spare unit availability.

Each of the factors described above requires study and integration into the overall O&M philosophy to be developed for the mobile radio system. With the exception of the time delay element for transport of a malfunctioning unit

to a central repair shop and the conditioning of minor maintenance facilities for extended right-of-way applications, the same considerations apply for the large or small local area mobile radio system.

B. O&M Structure and Operation

The implementation of a mobile radio system is in response to specific communication needs of the Borrower. Earlier sections of this Bulletin described resolving these needs into a logical statement of service criteria that the system is designed to meet. Operations and maintenance activities are derived from this criteria as the tool that assures continuous successful communications as planned, and the predicted life cycle of equipments and installations.

Power industry mobile radio systems normally consist of many mobile units and more than one fixed installation. Their activity and interaction with the daily objectives of the industry is work intensive; therefore, their productive economic value is high. For this reason it is cost-effective to structure an O&M organization in a manner that maintains a priority posture for mobile communications. Such a posture cuts across many business activities of the Borrower's organization, and in some instances may appear in contradiction to existing policy. Examples of this may exist in spare parts inventory control, emergency requisitions, parts procurement procedures, manpower assignments, transportation, manpower qualification, extended work assignments, cost accounting, and many other established areas representing procedures and policy for controlling the prime business activities. Each Borrower will represent a somewhat unique business activity structure; therefore, the organization of the O&M operation will differ. It is not the intent to describe a hard and fast O&M organizational structure herein, but rather to present a typical one that can be modified for individual needs.

The size of the average power industry mobile radio system qualifies it as a business operation requiring a dedicated manager. As such, he becomes the administrative and policy focal point for the O&M structure and operations. Ideally this position will not be involved in the technical decision process, depending upon specialists for such matters. To be effective for the O&M needs, this position requires authority to establish procedures and policy responsive to the mobile communications service anticipated for the system. In essence, this represents quick reaction to O&M needs that cannot be anticipated on economic or technical grounds, i.e. if an antenna tower is destroyed by a storm, the manager needs the authority to be able to replace it without lengthy competitive procurement procedures.

Reporting to the manager will be a supervisor of various operational groups having a vested interest in the mobile radio system. In all probability, these individuals will not be assigned solely to the

mobile radio operation, but they will be responsible for mobile radio expertise in the area of their power industry specialty. Figure III-1 represents a typical O&M organization structure. Only the Chief O&M Technician will have a line function under the O&M Manager. The title used herein is only to designate a basic technical position even though the Chief O&M Technician will have supervisory authority over all functions listed under its block. It is understood that these functions pertain only to the Mobile Radio System. Matters that require support of Engineering, Operations, or Administrative Services will be under supervisory coordination administered by the O&M Manager. Likewise, plans and programs under development by Engineering or Operations will be coordinated through the O&M Manager and Chief O&M Technician. This latter effort will permit contributions from the O&M personnel, and prepare this function for any impact that new plans and programs may exhibit.

It is assumed that the Mobile Radio System O&M Manager will be responsible for a budget. In order to control this economic aspect of O&M, direct access to the business functions listed under Administrative Services is necessary. It is assumed that one person in each affected department will be designated as the Mobile Radio System liaison specialist.

Normally, the O&M organization will be required to formulate policy and procedures that will assure adequate mobile radio communications service. These policies and procedures must complement those of the Borrower's prime business. They must also provide for authority covering emergency and priority conditions where system operation is paramount.

In order to accomplish the objectives of the Mobile Radio System O&M Management Office, it is desirable that it be assigned to an executive. As mentioned before, this individual would not require extensive mobile radio technical expertise, but should be able to make service oriented business decisions that complement the O&M needs of communications systems. Fast, positive reaction to unplanned situations is needed for continuous effective mobile radio service. Emergency conditions require authority to cut red tape and to cross organizational lines in order to bring proper resource to bear.

C. Manpower Requirements

The O&M plan must consider the manpower required to effect timely repairs. The planner must consider the amount of work load as well as the level of technical expertise required. The work load depends on the number of expected failures and the levels of maintenance. The level of expertise can be varied considerably, depending on the resources of the Borrower. Many systems can be maintained with a low level of maintenance which corrects failures in the field by

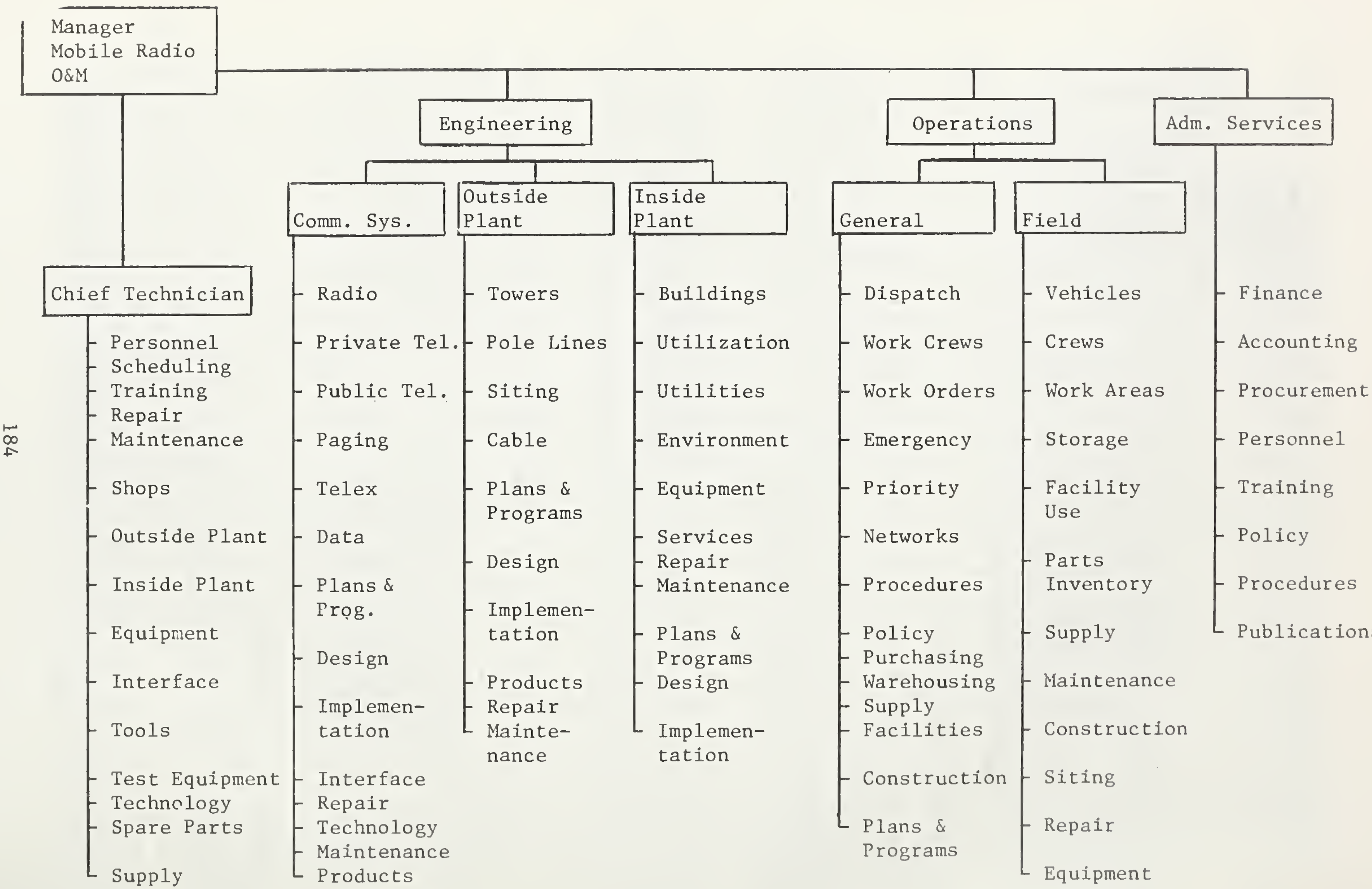


Figure III-1 Typical Organizational Structure for Mobile Radio System O&M Function

simply replacing units. Such a system is given depth by having greater levels of expertise available from the manufacturers, professional consultants, and service contractors.

As the system size and complexity increases, it often becomes more cost-effective to have the expertise available internally. As a minimum, at least one executive staff member should be capable of administering the O&M program. Beyond having one person responsible, the balance of the manpower requirements may be supplied by:

- Manufacturers under contract
- Consultants
- In house capability
- Contracts with O&M firms (if available)

The important concept is to ensure that sufficient manpower is available to effect all levels of repair required to maintain the system. Sufficient manpower is also required to implement required operational changes such as system expansion, circuit modifications and new services.

The Borrower planning to use internal resources for the mobile radio system will require technical personnel qualified to perform tests and maintenance for the following system components or specialties:

- Vehicular mobile radio
- Hand-carried mobile radio
- Pocket paging radio receivers
- Mobile relay station radio
- Base station radio
- Control heads (vehicular)
- Dispatch console mobile radio system control panels
- Commercial telephone system interface
- Private telephone system interface
- Private microwave system interface
- Emergency power and battery maintenance

- Vehicular radio installation

- Fixed radio installation

- Fixed antenna systems

- Vehicular electrical systems

And, as a prerequisite, such individuals assigned the authority to maintain transmitting equipment must be properly licensed by the FCC. With the possible exception of the telephone and microwave interfacing and emergency power specialties, a technical school radio graduate with 10 years of mobile radio field and bench experience should be very comfortable working with the other items listed. This type of individual can be classed as a senior mobile radio technician. Individuals who are qualified to do "black box" exchanges and physically related tasks such as mechanical inspections, electrical wiring, etc. for installation work, under moderate supervision can be classified as a technician learner or apprentice. There is a need for both ends of the skill scale in order to balance the economics of internal maintenance resources, as well as a larger percentage of manpower exhibiting intermediate skill levels. The ready availability of senior technical assistance will determine what this percentage will be. In general, the power industry mobile radio system serviced from one central repair and maintenance facility will have a higher percentage of intermediate skill level personnel than the extended right-of-way system. This latter requires highly skilled people assigned within reasonable travel distance throughout its route for backup of minor repair facilities personnel.

D. Training

Unless the selected O&M staff has direct experience with the system's equipment, some level of training is normally required. The following major training activities are often found most useful:

- Participation in the system design and equipment selection

- Formal training by manufacturers at their plant locations

- Participation in the installation and testing phases

- Assist in developing O&M program

- Formal classroom instruction

- On-the-job training (OJT) on an operating system

A well constructed training program should:

- Clearly state the end objectives of the program including resultant skill levels, cost, schedule, etc.
- Adequately define the skill level requirements of entering students
- Completely define all course activity in advance
- Prepare all instructional aids and student handouts in advance
- Employ instructors of greater skill than the course skill objectives
- Select personnel with teaching ability for instructors
- Arrange all housing and meals, etc. for students in advance to avoid course disruptions

The significant knowledge that should be imparted to the technical staff undergoing training consists mainly of:

- Skills requisite with required maintenance echelon levels
- Operational procedures of the O&M program

It is also advisable to train personnel over as wide a range of technical disciplines involved as practical. This tends to reduce the number of personnel required to operate and maintain the system. In cases of emergency, it also gives management a greater depth of skill to draw upon.

E. Support Requirements

1. Logistics

A major cost in an O&M program is material and logistics costs. The larger the system, naturally, the larger the complexity of the logistics operation. The major cost items other than salaries, overhead and financing are:

- Spares, parts and material inventory
- Test equipment and tools
- Vehicles and associated costs
- Repair, storage and office facilities
- Failed equipment replacements

In developing the O&M plan many options exist to cover the logistics requirements such as:

- Combined spares inventory with other existing inventories
- Contracting spares responsibility to vendors
- Rental of test equipment
- Contract out certain phases of O&M for equipment repairs
- Obtain long term equipment warranties with free and timely repairs clauses

The significant factor to consider is the fact that failures will occur and adequate means of effecting timely repairs must be planned for. The logistics involved can become complex and should receive close attention. On long systems, for example, it may be necessary to equip minor O&M facilities along the system to meet acceptable site access times.

Mobile radio systems, and especially those serving extended right of way areas of the power industry, inject a new dimension into logistics planning. This requirement can be called the parts depot concept. As mentioned before, minor maintenance facilities will be required along the extended right-of-way. Each of these will require mobility to attend to relay station maintenance; this requires convenient transportation and supply of repair parts. In short, a stocked maintenance vehicle which replaces its expended supplies from the minor maintenance facility inventory. Unless the number of mobile radio equipped vehicles supported from such a facility is large, i.e. 100 or more, this maintenance vehicle will also provide field support for them. In order to support the repair and maintenance supplies required by the minor maintenance facilities, a parts depot can be established at the central repair shop dedicated to the radio system(s). How many individuals will be required to support the depot concept must be established by the Borrower, based upon his existing ordering and accounting procedures and an estimate of approximately 1 line item transaction per week per radio in service. Because of the commonality of expendables for large mobile fleets, this transaction rate will decrease to 1/2 or 1/3 when 500 or more units are in service. The Borrower should note that the rates persented above are only a starting point for depot concept logistics planning, and that individual experience can modify these estimates.

F. Preventive Maintenance

In order to assure continued operation of a communications system over a prolonged period with a minimum of outage time, it is es-

sential that an adequate preventive maintenance program be established. The ultimate aim of this program should be the detection and elimination of possible component failures before these conditions cause system failure. For example, routine measurements at test points and panels of the equipment should be logged so that any changes can be detected and a component or module which is gradually becoming defective may be replaced. Thus, preventive maintenance differs from troubleshooting and repair in that its objective is to prevent trouble from occurring rather than to correct troubles after the equipment has failed. The two main phases of preventive maintenance are:

- Mechanical and physical inspection
- Electrical measurement and testing

Mechanical and physical inspections will eliminate a large percentage of future electrical troubles. Among the items which this phase would address are:

- Impairments due to mechanical vibration
- Mechanical integrity of connectors and assembly bolts and screws
- Mounting integrity
- Dust and dirt removal from equipment
- Rust and corrosion inspection
- Development of hot spots

The above are but a few of the items involved in mechanical and physical inspections.

The second phase of preventive maintenance is the electrical measurement and testing of the system. The electrical measurement and testing of the electrical maintenance program should include a complete test of overall system operation. Tests should be conducted periodically. Among the elements that may be tested are:

- Receiver signal to noise ratio/quieting
- Receiver sensitivity
- Control and signaling tone frequencies
- Tone detectors

- RF transmit frequency (FCC Requirement)
- RF transmit power (FCC Requirement) and reverse power
- Modulation deviation (RCC Requirement)
- DC voltages in equipment
- Transmit audio distortion
- Control head functions
- Foreign system interface signal levels
- Operation of standby power systems (fixed stations)
- Alarm and control functions (fixed stations)

G. Periodic Maintenance

Preventive maintenance of mobile radio system equipment should be performed at periodic intervals, such as quarterly, biannually, etc. The possibility of occurrence of trouble in equipment can be reduced greatly by following a definite maintenance schedule. The schedule should provide for visiting fixed stations at designated time intervals to make routine checks and to correct any conditions which might otherwise lead to failure. The inspector should make certain that the entire station is kept clean, and the equipment free from dust, dirt and corrosion. Personnel should perform the minor duties of maintenance and refer all problems or faults requiring specialized attention to the qualified and designated technical specialist.

It is essential that a complete systems check and station inspection be conducted at short intervals (i.e. weekly to monthly) for a reasonable time after the system is first installed. This procedure will expose the operational trends of the system's equipment and service degradation caused by component infant mortality. To accomplish an in-depth weekly maintenance procedure may require interruption of service for an interval of time, the length depending upon the particular equipment being checked. If service must be interrupted for this maintenance, tests should be scheduled during hours when communications traffic is normally light. It is also important that the scheduled maintenance be performed at the designated time. Inspection and maintenance logs should be started for each equipment at the fixed locations as soon as the units are powered up. These logs should contain records of key operating parameters that are measured at each periodic maintenance visit or whenever repair maintenance is required. Such records form a life history of a unit which is valuable in the determination of trends that can signal an impending system fault.

Periodic maintenance for vehicular radio equipment should be limited to the measurements required by the FCC Rules and Regulations and simple receiver sensitivity quieting tests. These can usually be accomplished without removal of the unit from the vehicle. The periodic maintenance philosophy for vehicular mobile equipment is best described as a "hands off" policy when equipment is performing satisfactorily. On the other hand, the vehicle installation should be accorded a rigorous periodic inspection program as a necessary adjunct to the availability prediction for the mobile radio equipment.

H. Test and Evaluation

Mobile radio system maintenance is a series of inspection and testing subjects leading to decisions ranging from "operationally compliant" to "major repair necessary". Each of the subjects can be assigned to some phase of the overall O&M program; some apply to all phases. Because the mobile radio system is comprised of equipment subjected to different operating conditions and operational responsibility, it is necessary to approach the inspection and testing requirements in terms of equipment classification. Three major classes exist within the average mobile radio system:

- Fixed station and fixed location equipment
- Vehicular mobile station
- Hand-carried mobile station

Each of these classes will require its own series of inspections and tests to assure functional performance within the system. But a commonality exists for all, which can be defined as the level of maintenance to be performed by a maintenance task. It is obvious that a time scheduled maintenance task performed on an operating fixed radio installation (that has demonstrated no problem history) should not be concerned with internal equipment tests that require precision test equipment used by the central repair facility. Therefore, it is necessary to establish levels for the tests and inspections to be performed, which are referred to as first, second, and third echelon maintenance.

1. Maintenance Echelons

Three echelons of maintenance normally planned for electronic communications systems can be defined as follows:

- First - on site (module replacement; minor external adjustment)
- Second - minor repair facility (major assembly or component replacement; minor internal adjustment)

- Third - central repair facility (factory type repair and overhaul; major alignment and adjustment)

Because the mobile radio system is a mix of interdependent technologies, physical properties and locations, it becomes necessary to provide mobility for all of the echelons. For example, some very sophisticated troubleshooting (i.e. testing) and repair may be necessary to isolate and fix a relay station antenna problem or a noise condition developing in a vehicle's electrical system. The Borrower will find that it is impossible to set an inflexible (i.e. firm policy) echelon structure because of the combination of fixed and highly mobile radio stations making up the system. In order to form the maintenance echelons to be responsive to firm policy and procedure criteria, it would be necessary to establish two parallel maintenance groups - one dedicated to fixed stations and other fixed location communications equipment, the other responsible for only vehicular and hand-carried mobile radios. Except for very large fleets, it is believed that such an organization of mobile radio system maintenance would be neither cost nor technically effective within the power industry.

The reason for developing the above rationale is to alert the Borrower to what may seem contradictions or not clearly defined responsibilities under the test and evaluation subject. In reality, it is a combination of the skill of the technician and the equipment class that determines the echelon of effort to be performed wherever the technician is working. The individual should be trained to recognize the level of maintenance he can adequately perform under a given condition. Therefore, within the discussion following, the philosophy of maintenance specialization is implied. The Borrower can extract from these paragraphs the situation and technical requirements necessary to plan this portion of the O&M program for the mobile radio system.

2. Levels of Test and Evaluation

In order to develop the first stage of the test and evaluation concept, it will be assumed that the communications system to be served consists of only fixed facilities; that the maintenance echelon plan is set. A second assumption is that maintenance levels for tests and inspections can be assigned to each echelon. Based upon these conditions, a matrix can be developed, assigning responsibility. Figure III-2 depicts this typical matrix.

For an active mobile radio system, the matrix takes on an extra dimension because of the mixture of fixed location and mobile units involved. Figure III-3 represents this concept

	Echelon of Maintenance		
Level of Performance Maintenance Testing & Evaluation	First	Second	Third
Operational - System	X		
Operational - Equipment	X	X	X
Functional - System	X		
Functional - Equipment	X	X	X
Mechanical - Installation	X	X	
Mechanical - Equipment		X	X
Assemblies - Equipment		X	X
Interface - System	X		
Specification - Equipment		X	X
Component - Equipment			X

Figure III-2 Typical Matrix for Level of Test & Evaluation Responsibility By Maintenance Echelon For Fixed Location Communications Facility

	Echelon of Maintenance								
	First	Second	Third	First	Second	Third	First	Second	Third
Location of Maintenance Testing	Field Site			Field Shop			Field Shop		
Level of Performance Maintenance Testing and Evaluation									
Operational - System	X	X				X			
Operational - Equipment	X	X		X	X	X	X	X	X
Functional - System	X	X				X			
Functional - Equipment	X	X	X	X	X	X	X	X	X
Mechanical - Installation	X	X		X	X	X			
Mechanical - Equipment		X	X		X	X	X	X	X
Assemblies - Equipment		X	X		X	X	X	X	X
Interface - System	X	X							
Specifications - Equipment						X	X	X	X
Component - Equipment		X	X		X	X		X	X

Figure III-3 Typical Matrix for Level of Test & Evaluation Responsibility By Maintenance Echelon For Mobile Radio System Facilities

as an extension of the maintenance echelon elements of Figure III-2 into the physical locations of system equipments. This shows that higher echelons of performance testing and evaluation can occur in the field because of the mobile equipment, and reinforces the need for maintenance vehicle capability as described in paragraph E.

3. Performance Parameters

Each equipment and type of installation (i.e. mobile, fixed, inside plant, outside plant etc.) will exhibit technical and physical parameters that can be measured or observed for comparison to some standard value or good practice. One of the first objectives of the O&M plan will be identification of specific and meaningful criteria, especially for field maintenance where independent decisions must be made as to technical quality and the need for higher order maintenance and repair. As a guide, typical lists of subjects follow, each representing a level of performance testing and evaluation. These lists should not be construed as all inclusive, as each system will have unique requirements.

a. Equipment Operational Parametric Subjects

- Transmitter power output (FCC requirement)
- Transmitter frequency (FCC requirement)
- Transmitter modulation (FCC requirement)
- Receiver sensitivity
- Receiver quieting
- Audio levels
- Antenna VSWR
- Squelch sensitivity
- Duplexer components

b. Equipment Functional Parametric Subjects

- Channel switching
- Channel scanning
- Tone coded squelch

- Tone (coded) carrier control (FCC requirement for defined conditions)
- Transmitter time out (FCC requirement for defined conditions)
- Carrier operated relay (control)
- Transmitter keying
- Carrier controlled squelch
- Squelch mode transfer switch (microphone hook switch)
- Volume control (receiver)
- Accessory switching (public address, horn etc.)
- Remote control
- Local control
- Relay operation
- Pilot and signal lights

c. <u>Equipment Mechanical Parametric Subjects</u>

- Connectors
- Cable lay and continuity
- Antenna integrity
- Antenna mounting
- Equipment mounts and mounting
- Covers and shields
- Dust and dirt exclusion/buildup
- Ventilation
- Moisture exclusion/entry
- Fuse block integrity
- Relays and contactors (fixed panels)
- Plug-in component integrity

- Wire lay and terminations
- Vibration effects
- Motors
- Solar radiation effects
- Insulation materials (wires, cables, circuit boards etc.)

d. <u>Equipment Assemblies Parametric Subjects</u>

- Receiver input
- Receiver intermediate frequency amplifier
- Receiver audio/squelch
- Receiver power supply
- Receiver channel elements
- Antenna transfer
- Transmitter channel elements
- Transmitter multiplier/driver/modulator
- Transmitter power amplifier
- Transmitter power supply
- Control modules (local, remote)
- Control head
- Dispatch control panel/modules/display
- Interface modules (foreign circuit, telephone etc.)
- Control signaling modules (remote)
- Redundant equipment transfer
- Duplexer tuning
- Diplexer tuning
- Circulator tuning

- Dummy load
- Antenna, fixed station
- Primary power source(s)
- Emergency power source
- Interface (amplifiers, hybrids, automatic switches etc.)

e. Equipment Specification Parametric Subjects

- Power supply
- Transmitter time out
- Oscillator(s) stability
- Metering facility
- Netting capability (frequency functions)
- Transmitter power control
- RF power output
- Load mismatch tolerance (transmitter)
- Spurious emissions (transmitter)
- FM noise and hum (transmitter)
- AM noise and hum (transmitter)
- Modulation (transmitter)
- Deviation limit control (transmitter)
- Audio sensitivity (transmitter)
- Audio distortion (transmitter)
- Audio frequency response (transmitter)
- Tone generator (sub-audible transmitter)
- Squelch tail elimination (transmitter)
- Channel switching (transmitter/receiver)

- Preamplifier (receiver)
- Quieting sensitivity (receiver)
- Usable sensitivity (receiver)
- Selectivity (receiver)
- Desensitization (receiver)
- Channel scanning (receive/control head)
- Intermodulation (receiver)
- Spurious signals (receiver)
- RF tuning (receiver input and IF circuits)
- Limiters (receiver)
- Audio power output (receivers)
- Audio distortion (receiver)
- Audio frequency response (receiver)
- Carrier operated squelch (receiver)
- Squelch tail elimination (receiver
- Tone operated squelch (receiver)
- Squelch gate (relay station)
- Drop-out delay timer (relay station)
- Tone decoder (relay station)

f. Equipment Component Parametric Subjects

The parameters existing under this level of test and evaluation are those that describe electronic circuit constants and component physical properties. These are primarily used in equipment troubleshooting to locate a failed or out of specification component, either passive (i.e. resistor, capacitor, inductor) or active (i.e. transistor, switch, relay, vacuum tube, microphone, loudspeaker, motor etc.). Without exception, first echelon maintenance activities will not be involved with equipment component parameters. The applicable values for specific component test and evaluation will normally be supplied as part of

the equipment manufacturers' documentation. A typical list of parametric subjects follows.

- Voltage (DC, AC, RF)
- Current (DC)
- Resistance
- Tension
- Clearance or spacing
- Lubrication
- Waveform
- Gain ($\pm$ dB or $\pm$ absolute)
- Frequency
- Distortion (transducer or circuit)
- Excursion (movement tolerance)
- Wear (tolerance)
- Noise
- Bandpass, bandstop, rejection, etc.

g. <u>System Operational Parametric Subjects</u>

- Remote control operations
- Audio transmission levels (telephone or microwave)
- Automatic control operations
- Timed operations
- RF field strength (fixed station)
- Antenna input power (transmitting)
- Audio distortion (telephone or microwave)
- Audio frequency response (telephone or microwave)
- Sequential operations (equipment)

- Control console operations (dispatcher)
- Alarms (status operations)

h. <u>System Functional Parametric Subjects</u>

- Control console (dispatcher) (switches, indicators, etc.)
- Alarm/status indicators
- Control head (vehicular mobile radio)
- Self-contained controls (hand-carried mobile radio)
- Tone code generators
- Tone code detectors
- Transfer switching
- Recorder operation

i. <u>Interface Parametric Subjects</u>

- Cable resistance (loop)
- Cable balance (telco)
- Cable leakage (insulation resistance)
- Cable crosstalk (telco)
- Cable frequency response (telco)
- Cable audio frequency levels (telco)
- Cable DC current (telco)
- DC relay control operation (remote control)
- Tone relay control operation (remote control)
- Signaling tone levels - receive and transmit
- Hybrid
- RF transmission lines
- Station wiring (distribution)

- Power transfer (emergency)
- Accessory units and cables etc.
- Microwave/multiplex levels
- Microwave/multiplex frequency response
- Primary power
- Connectors (RF, control, audio etc.)
- Alarm system
- Recording devices (audio, digital)
- Telephone (patch)
- Amplifiers (line)
- Common equipment (console audio etc.)
- Noise (foreign circuit)
- Signaling (foreign circuit)

4. Performance of Tests

Without exception, the performance of mobile radio tests and visual inspections requires that the unit be taken out of service. How long a particular unit will be unavailable is dependent upon the echelon of performance maintenance being executed. Ordinarily, if second or third echelon maintenance is called for, and it does not impact a vehicle, the mobile radio unit in question is exchanged with a spare, and normal communications capability is restored.

Fixed location stations and equipment, almost without exception, require that the equipment be placed in an out-of-service status in order to accomplish test and evaluation activities for all echelons. The duration of time involved depends to a degree upon the skill of the technician conducting the test and evaluation or repair. A certain degree of equipment exchange can be performed at fixed locations. This allows troubleshooting of a degraded unit at a repair facility without undue loss of station service. The quantity and types of spare equipment or modules required will be dependent upon the number of fixed locations and their design and, of course, the maintenance plan for the mobile radio system. In general, this plan will establish a time to repair factor for fixed installations as discussed earlier in paragraph III.A.1.b.

IV. BIBLIOGRAPHY

THEORETICAL UPPER BOUNDS ON SPECTRAL-SPATIAL UTILIZATION IN A CELLULAR LAND MOBILE COMMUNICATION SYSTEM, G.R. Cooper and R.W. Nettleton, IEEE International Symposium on Information Theory, Ithaca, N.Y., October 10-14, 1977.

MODULATION, NOISE AND SPECTRAL ANALYSIS, Philip F. Panter, Ph.D., McGraw-Hill Edition, 1965.

APPLICATION FOR DEVELOPMENTAL CELLULAR SYSTEM, Illinois Bell Telephone Company, FCC File No. 20115-CD-P-76, Federal Communications Commission, Washington, D.C., July 31, 1977.

MICROWAVE MOBILE COMMUNICATIONS, Jakes, John Wiley and Sons, New York, 1974.

LAND MOBILE COMMUNICATIONS AND THE DELIVERY OF PUBLIC SAFETY SERVICES, Edmondson, Communications for a Mobile Society, Cornell University, Ithaca, New York, 1977.

AN URBAN FIELD STRENGTH SURVEY AT THIRTY AND ONE HUNDRED MEGACYCLES, R.S. Holmes and A.H. Turner, Proc, IRE 24, pp. 755-770, 1936.

COMPARISON OF MOBILE RADIO TRANSMISSION AT 150, 450, 900, and 3700 MC, W.R. Young, BSTJ 31, pp. 1068-1085, 1952.

RADIO PROPAGATION FUNDAMENTALS, K. Bullington, BSTJ 36, pp. 593-626, 1957.

FIELD STRENGTH AND ITS VARIABILITY IN VHF AND UHF LAND-MOBILE RADIO SERVICE, Y. Okumura, E. Ohmori, T. Kawano, and K. Fukuda, (Tokyo), Rev. Elec. Com. Lab. 16, pp. 825-873, 1968.

INFLUENCE OF TERRAIN IRREGULARITIES AND ENVIRONMENTAL CLUTTER SURROUNDINGS ON THE PROPAGATION OF BROADCASTING WAVES IN THE UHF AND VHF BANDS, A. Kinase, NHK (Japan Braodcasting Corp.), Tech. Memo 14, pp. 1-64, 1969.

PROPAGATION OF VHF AND UHF ELECTROMAGNETIC WAVES OVER A GROVE OF TREES IN FULL LEAF, A.H. LaGrone, IEEE Trans. AP-25, pp. 866-869, 1977.

DIVERSITY TECHNIQUES FOR MOBILE RADIO RECEPTION, J.D. Parsons, M. Henze, P.A. Ratliffe, and M.J. Withers, IEEE Trans. VT-25, No. 3, pp. 75-85, 1976.

RADIO PROPAGATION AT FREQUENCIES ABOVE 30 MHZ, K. Bullington, Proc. IRE 35, pp. 1122-1136, 1947.

RADIO PROPAGATION ABOVE 40 MHZ OVER IRREGULAR TERRAIN, J.J. Egli, Proc. IRE 45, pp. 1383-1391, 1957.

COMPUTER PREDICTION OF SERVICE AREAS FOR VHF AND UHF BAND MOBILE RADIO SERVICES, J. Durkin, IEEE Trans. VT-26, No. 4, pp. 323-327, 1977.

INFORMATION TRANSMISSION, MODULATION, AND NOISE, M. Schwartz, McGraw Hill, New York, 1970.

REFERENCE DATA FOR RADIO ENGINEERS, Sixth Edition, Howard W. Sams & Co., Inc., 1975.

In December 1975, Congress passed the "Metric Conversion Act of 1975." This Act declares it to be the policy of the United States to plan and coordinate the use of the metric system.

The metric system, designated as the International System of Units (SI), is presently used by most countries of the world. The system is a modern version of the meter, kilogram, second, ampere (MKSA) system which has been in use for years in various parts of the world.

To promote greater familiarization of the metric system in anticipation of the U.S. converting to the system, REA is including metric units in its publications. This bulletin has, therefore, been prepared with the International System of Units (SI) obtained from ANSI Z 210-1976 - Metric Practice. Approximately equivalent Customary Units are also included to permit ease in reading and usage, and to provide a comparison between the two systems.

*U.S. GOVERNMENT PRINTING OFFICE : 1978 0-720-323/3367